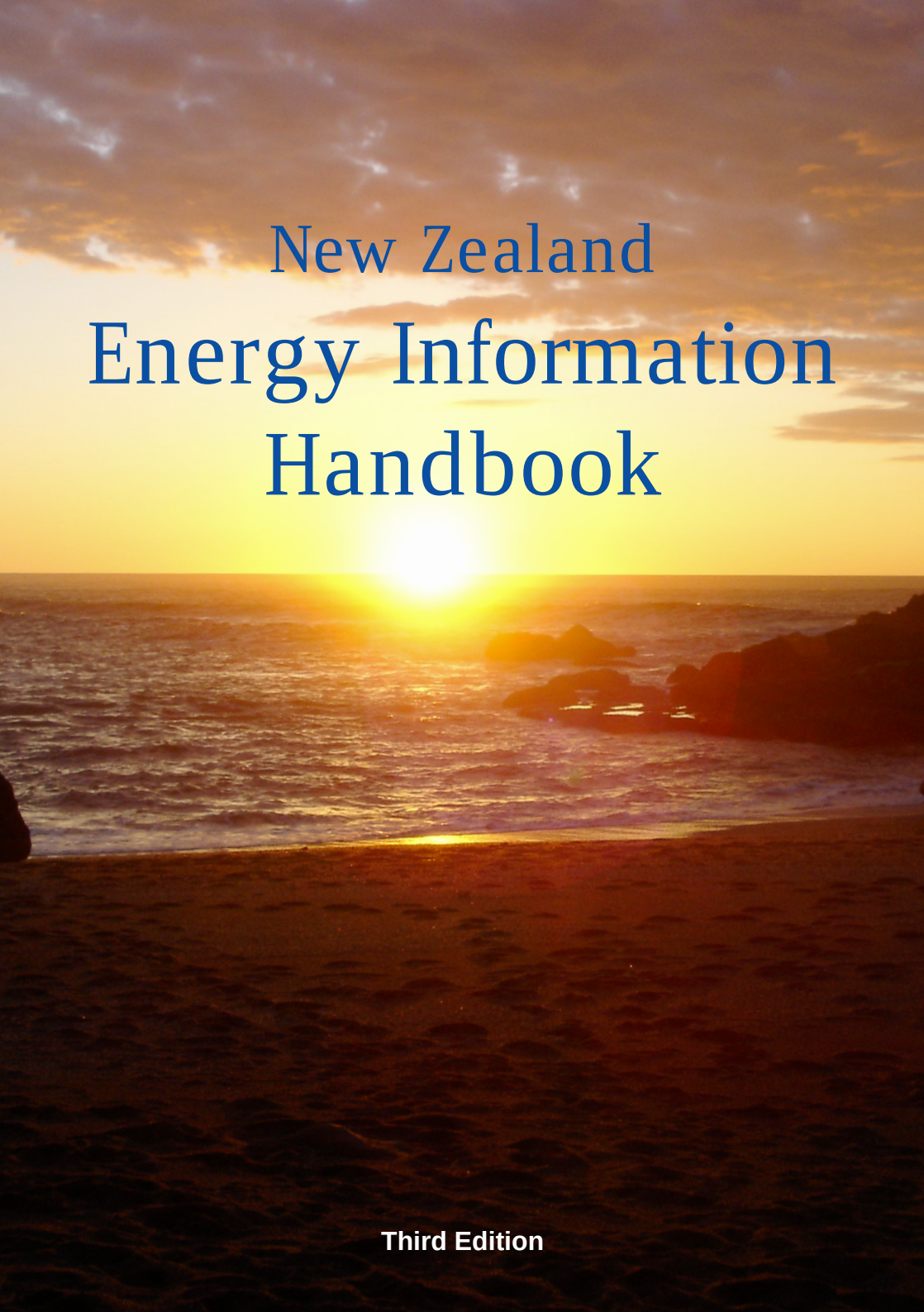

New Zealand Energy Information Handbook

Third Edition

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Preface

This Energy Information Handbook brings together in a single, concise, ready-reference format basic technical information describing the country's energy resources and current energy commodities.

The editor of the second edition of the Handbook published in 1991, James Baines, was responsible for editing a similar volume in 1984 under the auspices of the New Zealand Energy Research and Development Committee. This is the third revised and expanded edition, published for the first time by the New Zealand Centre for Advanced Engineering (CAENZ).

CAENZ was established in 1987 as the Centre for Advanced Engineering (CAE) to mark one hundred years of teaching engineering at the University of Canterbury. Over the years, guided by 'for the public good' principles, CAENZ has played a strong knowledge-broking and facilitating role within New Zealand's engineering and technology sectors, seeking to enlarge this country's technological capability in areas of national importance.

As with the second edition, a new Handbook is overdue for several reasons. The original volume was prepared at a time when the gas sector in particular was in a state of rapid evolution. It is a very different now and so are the energy commodities involved. Since 1984, the energy sector has been re-regulated, corporatised and privatised to varying degrees. Access to definitive information, even of a technical rather than a commercial nature, remains problematic for many. Climate Change and the depletion rate of fossil energy resources, more widely recognised now than when the second edition was published, add to the pressure of finding and using energy resources with the utmost efficiency and with due regard to the environmental consequences.

The data contained in this Handbook have been selected as being suitable for analyses and investigations at the planning and policy level, and for general consumer and student enquiries. The two main aims served by this Handbook are to encourage the widespread and consistent use of a uniform data set, relevant to New Zealand, and to familiarise users who do not have a technical background with the important factors that affect the appropriateness and accuracy of energy data.

Interest in strategic energy issues is intensifying even more. Informed public debate depends on access to authoritative data. It is heartening to observe a continuation of support for making good technical data publicly available among energy sector organisations. This Handbook is a tribute to the cooperativeness of many individuals in the energy sector.

The Handbook is not intended to be an energy compendium, and does not contain energy statistics or other data that will date quickly. There are several alternative sources for information of this type, such as the Ministry of Economic Development Energy Data File (www.med.govt.nz) and the EECA website (www.eeca.govt.nz).

Handbook Updating

As always, there are gaps in this database, attributable in the main either to commercial sensitivities (primary resource data) or to the absence of basic information (end-use data). In time these gaps may be remedied.

It is also likely that users of the Handbook will be able to identify possible additions or improvements to be incorporated in future editions. This Handbook will continue to be reviewed and updated from time to time to accommodate changing circumstances in New Zealand's energy scene, and additional user requirements. Comments and suggestions from users would be welcomed. These can be sent to:

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1 Introduction

New Zealand focus and international conventions

Energy is derived from many different sources, measured in different units, and reported in a variety of terminology. The definitions, conversion factors, and tables of energy data that follow are aimed at minimising errors and inconsistencies of energy accounting that might stem from such differences.

This Handbook brings together data based on general practices followed in New Zealand in recording and compiling information on energy stocks and usage. The units of measurement and the interconversion factors presented take into consideration the wider perspective of international practices.

The Handbook details characteristics of energy types, fuel commodities and rates of production. It does not contain historical, time-series data that would very quickly become dated.

In a few cases (e.g. for manufactured gas data), information has been retained on energy commodities no longer in use. This has been done to provide for situations requiring historical analysis.

Units and conversion factors

In the past, a variety of measurement systems has been in use around the world. The Systeme Internationale (SI) has become established as the predominant coherent system of units, even though other systems remain in use in certain specialist situations. Users of the data in this Handbook are urged to convert all energy data to Joules (and multiples thereof) and to adopt SI conventions generally (Refer to NZ Standard 650:1973).

Conversion factors between the various systems of units appear in two sections of this Handbook. Those most directly involved in energy accounting procedures (energy/work equivalents, power equivalents, and calorific value equivalents) are presented early in the Handbook (Section 2) before the energy commodity data. Conversion factors for other physical units (e.g. volume, mass, density, etc) are presented at the back (Section 16).

Levels of accuracy

The energy data contained in this Handbook are intended for use primarily in general energy accounting procedures, not in specialist scientific calculations. Individual numerical values are in some cases expressed using more significant figures than the confidence limits would indicate is appropriate. The premise used to justify this is that it is quite acceptable computational practice to carry more significant figures through a sequence of calculations so long as the end result is appropriately truncated to reflect the ultimate confidence limits. It is therefore expected that the user will follow this suggested practice.

2 Units and Energy Conversion Factors

SI units of measurement

The seven SI base units of measurement are given in Table 2.1, while Table 2.2 lists a further four derived SI units of particular relevance in the measurement of energy quantities.

Metric prefixes

One of the numerous advantages of any metric system is its set of prefixes for indicating multiples of common units.

The recommended prefixes listed in Table 2.3 are those indicating multiples and sub-multiples that differ from a unit in steps of 10^3.

Energy commodity units in popular usage

The units in which energy commodities are most commonly measured are numerous.

Units of mass are used as the basis for measurement of most solid and most non-commercial fuels (e.g. sawdust, other waste products) and, in some instances, of liquid fuels. Units of volume are used in the measurement of liquid fuels, certain non-commercial fuels (e.g. fuelwood), and gas.

Also used in the measurement of gas are calories and British thermal units (Btu).

Physical quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Table 2.1: SI base units

Physical quantity	Unit	Symbol	Derivation
Force	newton	N	kg m s^{-2}
Pressure	pascal	Pa	N m^{-2}
Work, energy, heat	joule	J	N m
Power	watt	W	J s^{-1}

Table 2.2: Derived units. The column headed 'derivation' gives the expression of the unit in terms of SI base units or of SI units with special names.

Prefix	Symbol	Factor
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

Table 2.3: Metric prefixes, symbols and factors

Other units commonly employed in the measurement of energy or energy commodities are the kilowatt hour (kWh), and multiples thereof, for electrical energy, and the Joule (J), which links heat and work.

Energy and work equivalents

The SI unit of energy is the Joule. The Joule is the work done or the energy expended when a force of one newton moves the point of application a distance of one metre in the direction of that force. (Source: SANZ 6501:1973)

In other metric systems calories are used. One calorie is the energy needed to increase the temperature of a gram of water by 1 degree Celsius but, as this depends on the starting temperature and other variables, several definitions are in use. The most common are the thermochemical calorie (cal_{th}), defined as exactly 4.1840 joules by the US Bureau of Standards in 1953, and the International Steam Table calorie (ITcal), defined as exactly 4.1868 joules by the Fifth International Conference on Properties of Steam in 1956. These should not be mistaken for the biological calorie, used in the measurement of food energy, which is in fact equal to 1000 physical calories.

The Imperial and American systems use British thermal units (Btu; 1 Quad = 10^{15} Btu) or therms and sometimes kilowatt hours (kWh) or multiples thereof. Other measures of work include British and metric horsepower-hours (hp-h), and the foot-pound (ft-lb). The interrelationships between the various units for measuring energy are presented in Table 2.4.

Power equivalents

Power is the rate of doing work or the

To convert **to:**	J	ITcal	kWh	Btu
from:	*multiply by*			
Joules (**J**)	*1*	0.2388	2.778×10^{-7}	9.478×10^{-4}
International Steam Table calorie (**ITcal**)	4.1868	*1*	1.163×10^{-6}	3.968×10^{-3}
kilowatt-hours (**kWh**)	3.6×10^{6}	8.6×10^{5}	*1*	3412
British Thermal Units (**Btu**)	1055.1	252	2.931×10^{-4}	*1*
Horsepower hours (**hp-h**)	2.685×10^{6}	6.412×10^{5}	0.7457	2544
Cheval-vapeur hours (**cv-h**)	2.648×10^{6}	6.324×10^{5}	0.7355	2510

Table 2.4: Energy and work equivalents

rate of energy flow. The SI unit of power is the watt (W), defined as a rate of one Joule per second. Frequently it is measured in multiples of the watt: kilowatt (kW), megawatt (MW), gigawatt (GW), etc. In other systems it is variously measured in such units as horsepower, cheval-vapeur, metric horsepower, kilogram-force metres per second or foot pounds per second.

Power multiplied by the time during which it applies equals work. The interrelationships between the principal measures of power are given in Table 2.5.

Calorific value equivalents

The energy content of a fuel is usually given as the heat released on complete combustion of a given quantity of the fuel in air or oxygen. It is often referred to as the calorific value or the specific energy. Non combustible energy forms are sometimes expressed in terms of their heat equivalents.

Energy content can be expressed on either a unit mass or unit volume basis. Thus the basic SI units are joules per kilogram or joules per cubic metre. The British system of units employs the Btu per pound or per cubic foot. In either system, each of the combustion fuels has two values – an upper *gross* value and a lower *net* value. The difference between the two is the energy necessary to evaporate water that is either present in the combustible material (moisture content), or formed in the combustion reaction where hydrogen and oxygen combine. The evaluation of a net calorific value is made on the assumption that the water vapour is not recondensed within the region of heat requirement and thus this latent heat of vaporisation is not available to the process for which the fuel was burned. Almost invariably this is the case. Net calorific values indicate the amount of useful heat made available on combustion. Thus net calorific values are considered a more useful criterion by which to compare the energy contents of different fuels. Nevertheless, for energy accounting purposes and generally in New Zealand statistical recording, the convention is to use gross calorific values.

In general, the difference between gross and net calorific values is of the order of 6%-8% in liquid fuels and 10% in gaseous fuels. In coals, the greater physical variability amongst products (in contrast with petroleum products) gives rise to a much wider range of gross/net differences,

To convert to:	**kW**	**kgf-m s^{-1}**	**ft-lb s^{-1}**	**hp**	**Metric hp**
from:	*multiply by*				
kilowatts (**kW**)	*1*	102	737.6	1.341	1.360
Kilogram-force.metre/ second (**kgf-m s^{-1}**)	9.807×10^{-3}	*1*	7.233	1.315×10^{-2}	1.333×10^{-2}
foot.pound/second (**ft-lb s^{-1}**)	1.356×10^{-3}	0.1383	*1*	1.818×10^{-3}	1.843×10^{-3}
horsepower (**hp**)	0.7457	76	550	*1*	1.014
metric horsepower (**metric hp**)	0.7355	75	542	0.9863	*1*

Table 2.5: Power equivalents

To convert from:	to:	MJ/kg *multiply by*	Mcal/kg	Btu/lb
MJ/kg		*1*	0.2388	429.9
Mcal/kg		4.1868	*1*	1800
Btu/lb		2.326×10^{-3}	5.556×10^{-4}	*1*

Table 2.6: Calorific Value Equivalents – Mass Basis

To convert from:	to:	MJ/m^3 *multiply by*	MJ/litre	$Mcal/m^3$	Mcal/litre	Btu/ft^3
MJ/m^3		*1*	0.001	0.2388	2.388×10^{-4}	26.84
MJ/litre		1000	*1*	239	0.2388	26839
$Mcal/m^3$		4.1868	4.187×10^{-3}	*1*	0.001	112.4
Mcal/litre		4186.8	4.1868	1000	*1*	112370
Btu/ft^3		3.726×10^{-2}	3.726×10^{-5}	8.899×10^{-3}	8.899×10^{-6}	*1*

Table 2.7: Calorific Value Equivalents – Volume Basis

from 2% to 15% or more. The interrelationships between the most common units are given in Tables 2.6 and 2.7.

IEA energy equivalents

The International Energy Agency (IEA) has for some years been involved in producing standardised national energy balance sheets for member countries, all expressed in a common unit. Traditionally, this common unit has been 'tonnes of oil equivalent' (toe), since quantities of oil are an important element in policy decisions.

A tonne of oil equivalent is defined as 10^7 kcal, a convenient measure although somewhat below the average heat content of crude oil. The change from using the original unit to tonnes of oil equivalent implies choosing coefficients of equivalence between different forms and sources of energy. In all cases the conversion factors used are based on net calorific values.

In consultation with officials from national administrations, the IEA has adopted separate factors for the main energy types produced in each member country. Coal and gas are expressed in terms of the quantity of oil which gives the same amount of heat. Hydro electricity is converted to oil equivalents on the basis of the energy content of the electricity generated at the turbines (i.e. at 100% efficiency), while geothermal and nuclear electricity are converted to oil equivalents on the basis of the steam input to the turbines and average efficiencies of 10% for geothermal electricity generation and 33% for nuclear electricity generation. Table 2.8 summarises general IEA conversion equivalents and Table 2.9 gives the coefficients currently appropriate to New Zealand.

Some examples of unit conversions

To convert from a given unit to its corresponding SI unit, enter the relevant

Energy Form	Base unit	toe/Base unit
Refinery gas	tonne	1.150
Ethane	tonne	1.130
LPG	tonne	1.130
Aviation gasoline	tonne	1.070
Motor gasoline	tonne	1.070
Jet fuel	tonne	1.065
Kerosene	tonne	1.045
Naphtha	tonne	1.075
Gas/diesel oil	tonne	1.035
Other products, including heavy fuel oil	tonne	0.960
Petroleum Coke	tonne	0.740
Natural gas	GJ net	0.0239
Hydro-electricity	MWh	0.086
Nuclear electricity	MWh	0.2606
Geothermal electricity	MWh	0.860
Electricity from solar, wind, tidal, wave and other non-thermal sources	MWh	0.086
Other solid fuels	GJ net	0.0239

Table 2.8: IEA energy equivalents – general (Source: IEA)

table from the left, along the row of the given unit. The appropriate multiplier will be in the first column. Several examples follow.

(1) To convert kWh of electrical energy to Joules, enter Table 2.4 at the third row, and read the multiplier in the first column under Joules. In this case the multiplier is 3.6×10^6. Thus 17 kWh = 17 x (3.6×10^6)J or 61.2×10^6 J or 61.2 MJ.

(2) To convert horsepower to kilowatts, enter Table 2.5 at the fourth row, and read the multiplier in the first column – 0.7457. Thus 1.5 horsepower = 1.5 x 0.7457 kW or 1.12 kW.

(3) To convert calorific values expressed in Btu/lb to the corresponding SI unit, enter Table 2.6 at the third row, and read the multiplier in the first column under MJ/kg. In this case the multiplier is 2.326×10^{-3}. Thus 10,300 Btu/lb = 10,300 x (2.326×10^{-3}) MJ/kg or 23.96 MJ/kg.

(4) To convert calorific values expressed in Mcal/litre to MJ/m^3, enter Table 2.7

at the fourth row, and read the multiplier in the first column – 4186.8. Thus 0.015 Mcal/litre equals 0.015 x 4186.8 MJ/m^3 or 62.8 MJ/m^3.

Energy Form	toe/tonne
Crude oil	1.0248
Natural gas liquids	1.0903
Refinery feedstocks	1.0323
Bituminous coal and anthracite	
Production	0.6941
Imports	0.6941
Industry use	0.6941
Average	0.6941
Sub-bituminous coal	
Production	0.5054
Electricity generation	0.5059
Industry use	0.5059
Average	0.5057
Coking coal	
Production	0.7337
Exports	0.7337
Industrial use	-
Average	0.7337
Lignite coal	
Production	0.3325
Industrial use	0.2912
Average	0.3118
Coal products	
Coke oven coke	0.649
Gas coke	0.8373

Table 2.9: IEA energy equivalents for New Zealand (Source: IEA)

3 Coal

Character of the resource

Coal is a combustible sedimentary rock containing both organic and mineral matter. The organic matter is derived from plant material accumulated under conditions which have prevented complete decay. The coalification process results from subsequent burial of this plant material, forming a complex mixture of chemical compounds containing carbon, hydrogen and oxygen together with smaller amounts of nitrogen, sulphur and trace elements. The mineral matter consists chiefly of clay minerals, mineral forms of sulphur (mostly pyrite) and smaller amounts of other minerals. Moisture is also an important constituent.

Coals have a wide range of properties that influence the way in which they are used. These characteristics are measured by a wide range of analytical techniques. There are three main factors which determine coal properties:

- Type – variation in the original plant material from which coal is derived and the amount of decay that occurred before eventual burial.
- Rank – difference in the degree of burial of the original plant material which affects the temperature and pressure conditions that existed during coalification.
- Grade – the amount of contamination by inorganic material during deposition which results in variations in mineral matter contained in coal. High-grade coal contains little mineral matter, whereas lower-grade coal contains more mineral matter, mainly derived from mud in the original peat swamp.

Increasing rank results in progressive and irreversible changes in the chemical and physical properties of the coal, in the generalised sequence of peat → lignite (brown coal) → sub-bituminous coal → bituminous coal → semi-anthracite → anthracite. The changes in rank-induced properties between these general groups is continuous, but uneven. The ASTM coal classification system is generally used in New Zealand (see Figure 3.1).

The coal sector in New Zealand

Coal is New Zealand's most abundant fossil fuel and currently supplies about 12.5% of primary energy supply. Coal plays an important role in New Zealand's energy mix, both because of the extent of the proven indigenous resource and its ability to improve fuel diversity and energy security. As well as being used for electricity generation, coal is used as a heat source in the dairy, meat and timber industries, and as a reagent/heat source in cement and steel manufacture.

Production in 2006 was 5.8 Mt or 153 PJ/year from about 26 mines of varying size. Coal mines are located in the Waikato (servicing principally the Glenbrook mill, the Huntly power station and several major industrial customers), Otago/Southland (servicing mainly local

Region	2006 Production (million tonnes)
Waikato	2.290
West Coast	2.999
Canterbury	0.004
Otago and Southland	0.475
TOTAL	**5.768**

Table 3.1: New Zealand coal production 2006

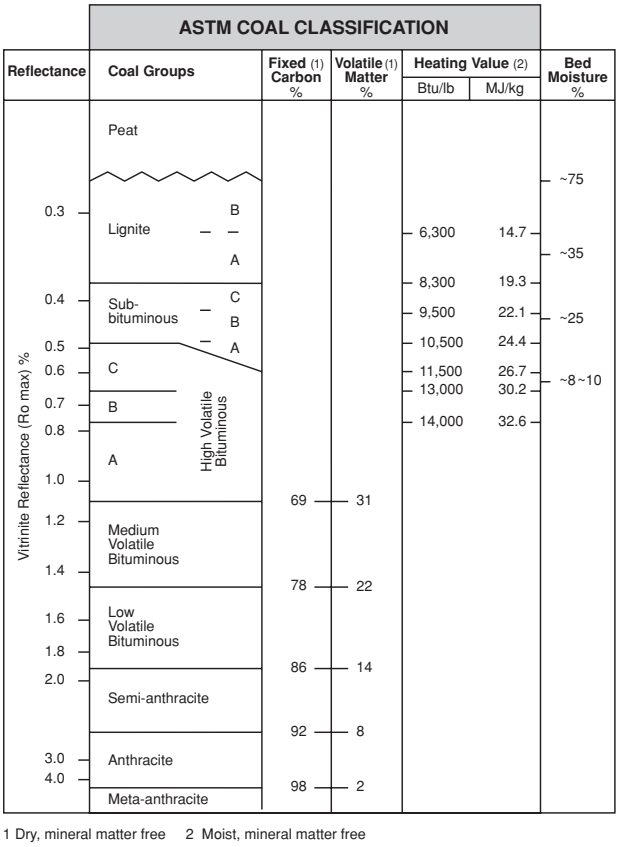

Figure 3.1: ASTM coal classification chart

industrial and domestic markets) and on the West Coast (servicing mainly export markets). Rotowaro in the Waikato (1.5 million tonnes per year) and Stockton on the West Coast (2 million tonnes per year) are the largest producers.

Genesis Energy's 1000 MW dual coal/gas-fired station at Huntly, is New Zealand's only coal-fired power station. It can supply up to 15% of New Zealand's electricity requirements, consuming up to 3 Mt of coal depending on hydro inflows and gas supply.

Premium grade bituminous coals from the West Coast of New Zealand are exported for use in the chemical and steel industries. Properties such as very low ash and sulphur contents, and extremely high swelling characteristics, make them suitable for blending with lower-quality coking coals. For this reason, they can command high prices internationally. In 2006, coal exports were 2.5 million tonnes, generating export earnings of US$250 million. West Coast coking coals are not suitable for the Glenbrook steel mill, which uses Waikato coal in a unique direct reduction process, or for the Huntly power station.

Coal region	Age of coal	Seam thickness – typical (max) metres	Coal rank ASTM	Ash content dry basis[1]	Sulphur content dry basis
Northland	Late Eocene	2 (8.1)	sub-bituminous A	2.5-8%	1-5%
Waikato (Northern)	Late Eocene	4-10 (30)	sub-bituminous C-A	2-10%	0.2-0.3%
Waikato (Southern)	Late Eocene-Oligocene	1-5 (14)	sub-bituminous C	5-20%	0.3-8%
Taranaki	Early Miocene	1-3 (4.5)	sub-bituminous B-A	2-12%	1-4.5%
Nelson-West Coast	Late Eocene	2- 8 (24)	sub-bituminous C - semi-anthracite	0.5-6%	0.3-7%
	Late Cretaceous	3-6 (18)		1-5%	0.3-1%
Canterbury	Late Cretaceous-Middle Eocene	1-5 (20)	sub-bituminous - semi-anthracite	1.2-6%	0.5-2%
Otago (Eastern)	Late Cretaceous-Late Eocene	2-5 (30)	lignite - sub-bituminous B	3-8%	0.25-6%
Otago (Central)	Oligocene-Early Miocene	20-60 (79)	lignite	3-20%*	0.2-0.6%*
Southland (Western)	Late Cretaceous-Late Eocene	4-14 (23)	sub-bituminous A-C	1-8%	0.3-0.6%
Southland (Eastern)	Oligocene to Miocene	2-5 (13)	lignite	3-20%*	0.2-0.6%*

1 in-ground basis

Table 3.2: Regional variation of coal properties (Source: www.crownminerals.govt.nz)

New Zealand coal properties

There are major contrasts in properties – rank, type and grade – between the coals from different New Zealand coalfields. There can even be considerable variation of properties within a single deposit or even within one mine. This variation of properties is the result of the different, and sometimes complex, geological histories of many New Zealand coalfields, especially on the West Coast of the South Island.

New Zealand coals range from very high-moisture lignite to very low-moisture bituminous coal and minor anthracite, which covers the full range of coal rank.

Detailed information on the properties of some New Zealand export coals can be found on the Solid Energy NZ Ltd website (www.coalnz.com).

New Zealand coal resources

New Zealand's coalfields have been well explored and the country's coal resources are well known (see Figure 3.2). Extensive resources are present in the Waikato and Taranaki regions of the North Island, and in the West Coast, Otago and Southland regions of the South Island. The total in-ground resource for New Zealand is estimated to be about 15 billion tonnes.

North Island coalfields are located principally in the Waikato and northern Taranaki with in ground resources totalling about 2 billion tonnes. The Waikato deposits are by far the most important because of their size and location close to centres of demand. Almost all of the 2.3 million tonnes currently produced from the Waikato each year is mined from the Rotowaro and Huntly fields, accounting for about 40% of New Zealand's total annual

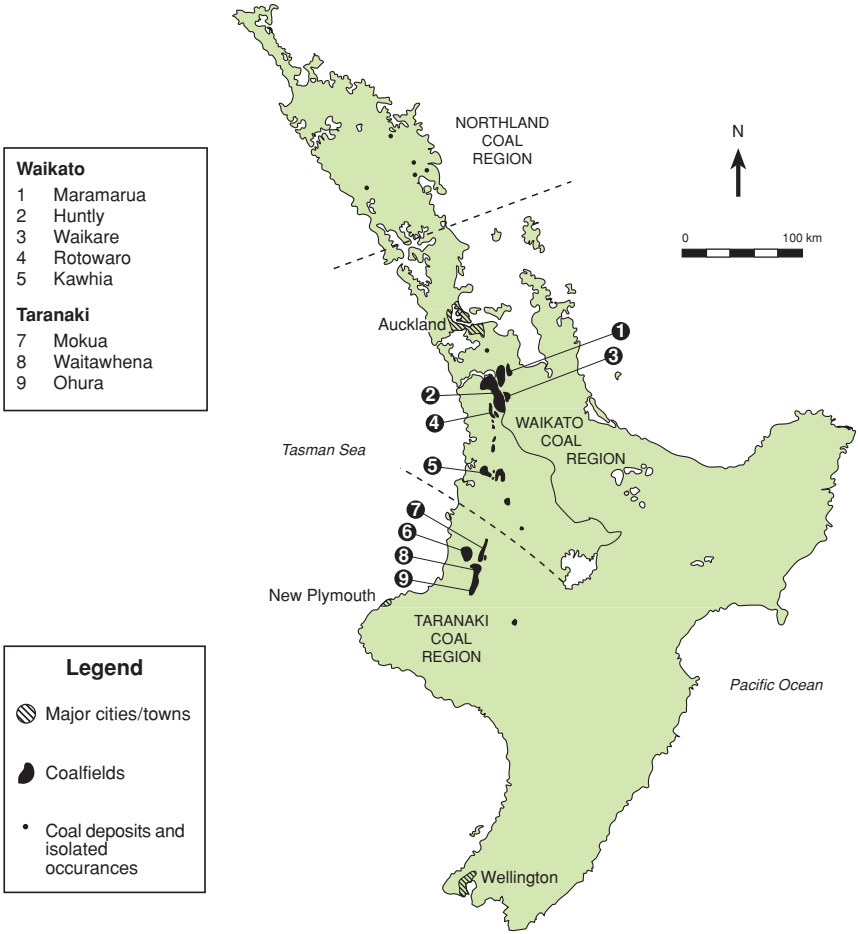

Figure 3.2(a): Distribution of New Zealand's coal resources – North Island

production and 70% of production for domestic consumption. The steel mill at Glenbrook and the thermal power station at Huntly are the main users. Recent expansion in Waikato coal production was driven by demand to fuel the Huntly power station, which has switched from gas to primarily coal.

The West Coast contains New Zealand's only bituminous coals. The Buller, Greymouth, Pike River, and Reefton coalfields are the most economically important coalfields. Some West Coast coals are exceptionally low in mineral contaminants which, together with high fluidity and swelling properties, allow these coals to command premium prices in international metallurgical coal markets. Coal-in-ground resources for the region are about 1 billion tonnes. Over three-quarters of recoverable reserves are

Figure 3.2(b): Distribution of New Zealand's coal resources – South Island

in the Greymouth (mostly underground) and Buller (mostly opencast) coalfields. The Pike River coalfield is under development and is slated to start production in 2008.

Most of New Zealand's coal resources are in the south of the South Island. Otago coalfields include very large lignite deposits in Central Otago, the Kaitangata coalfield south of Dunedin, and several smaller coalfields. Southland coalfields include the huge lignite deposits underlying the Eastern Southland plains, the Ohai coalfield in central Southland, and a number of lesser coalfields.

The South Island lignites are by far New Zealand's biggest known single energy resource. Lignites make up 80% of New Zealand's coal resources by tonnage and two-thirds by energy content. Resources of

over 6.2 billion tonnes have been proven to be mineable, equivalent to 74,000 PJ of energy or about 20 times the original energy content of the Maui gas field. These deposits can be used for large-scale conversion to petrochemicals, liquid fuels and electricity and have the potential to meet current New Zealand energy needs for several hundred years.

Recoverable coal quantites for sub-bituminous and bituminous coals are less certain, and published figures are unreliable. The economic availability of coal depends on several factors, including:

- resource size and location;
- market size, location and security;

Region/Coalfield	Coal-in-ground resource Mt[1]
Northland	2.5
Waikato-King Country	2100
Taranaki	380
Total North Island	*2500*
Nelson	1.5
West Coast	960
Canterbury	3.6
Central Otago region	1400
Eastern Otago	1300
Eastern Southland	9400
Western Southland	190
Total South Island	*13 000*
Total New Zealand	***15 500***

1 Allowances have been made for production since 1994, but not for exploration since then. All figures are rounded to two significant figures.

Table 3.3: New Zealand coal resources. (Source: Barry, JM, Duff, SW and Macfarlane, DAB, 1994. "Coal Resources of New Zealand". Resource Information Report 16, Ministry of Commerce)

- market energy prices;
- distribution infrastructure and cost;
- quality of geological information; and
- quality of mine planning.

Coal analysis

Variation in the properties of coal may be characterised by a range of physical and chemical laboratory tests. In addition, petrological analysis is used to describe variations in coal type for certain purposes.

The data gained is used to describe and classify coals for utilisation purposes and for the study of the geological history of coal and coal-bearing sediments, which has application in coal mining and utilisation assessment as well as to coal and petroleum exploration.

Most of the methods of coal analysis are highly empirical. They involve strict adherence to certain specified conditions, such as particle size, temperature, time and rate of heating, conditions of the atmosphere in which the test is conducted, and size and shape of sample container in which the tests take place. It is essential that the details of these specified conditions be adhered to closely, in order to obtain reproducible results. The establishment of procedures that are recognised as standard and approved by authoritative organisations are of the utmost importance in coal analysis.

Standard coal tests for the characterisation of coal, and to determine their suitability for particular applications, have been developed by the various standards associations of different nations. In New Zealand, ISO (International Organisation for Standardisation) procedures are generally now used, although ASTM (Amercian Standard for Testing Materials)

and British Standard Test methods have been extensively used in the past.

Analysis results of New Zealand industrial coals is shown in Table 3.4.

Ultimate analysis

This measures coal composition in terms of its principle constituent elements – carbon, hydrogen, nitrogen, sulphur and oxygen (by difference from 100). The analysis is generally reported on a dry, ash-free basis, assuming moisture and ash to be dilutents of the coal substance, so that measurement of ash is a pre-requisite.

Name of Mine	Moisture	Ash	Volatile Matter	Fixed Carbon	Gross Calorific Value	Net Calorific Value	Sulphur	Crucible Swelling	Ash Fusion Temp Hemi	Volatile Matter Dry Ash Free	Gross Calorific Value Dry Ash Free
	%	%	%	%	MJ/kg	MJ/kg	%	No.	˚C	%	MJ/kg
Waikato											
Huntly East No. 1	20.6	3.8	34.7	41.1	22.93	21.55	0.21	0	1280	45.8	30.29
Kopako	26.7	3.9	33.4	36.0	20.17	18.75	0.15	0	1220	48.1	29.06
O'Reilly's	19.8	5.8	34.6	39.8	22.13	20.80	0.23	0	1260	46.5	29.74
Rotowaro	21.0	4.6	34.4	40.1	22.24	20.88	0.23	0	1210	46.1	29.87
Buller											
Cascade	9.7	1.6	36.1	52.7	29.96	28.65	0.60	3 1/2	1290	40.6	33.76
Heaphy	18.1	3.8	36.8	41.3	24.20	22.85	2.25	0	1140	47.1	30.99
New Creek	18.9	1.6	36.4	43.2	23.93	22.57	4.2	1/2	1120	45.7	30.08
Stockton	8.1	2.9	31.0	58.0	31.65	30.40	1.9	9	1550	34.8	35.56
Reefton											
Echo	5.9	2.1	38.7	53.2	30.87	29.61	0.46	3 1/2	1500	42.1	33.57
Giles Creek	29.4	2.8	32.1	35.7	19.04	17.60	0.42	0	1260	47.4	28.09
Island Block	6.6	2.1	39.3	51.9	30.46	29.19	1.51	4	1220	43.1	33.39
Terrace	15.1	5.1	36.6	43.2	24.98	23.71	1.11	1	1180	45.9	31.28
Greymouth											
Roa	6.7	6.5	18.5	68.3	31.95	30.77	0.27	9+	1360	21.3	36.82
Spring Creek	10.2	2.5	37.6	49.7	29.83	28.53	0.35	2 1/2	1230	43.1	34.19
Canterbury											
Mt Somers	28.1	11.6	29.3	31.1	17.71	16.35	2.50	0	1300	48.6	29.32
Canterbury Coal	27.5	3.0	32.4	37.1	20.84	19.40	0.38	0	1300	46.6	29.99
Otago											
Harliwich	28.8	6.3	38.2	26.6	18.52	17.11	0.43	0	1290	58.9	28.54
Kai Point	30.4	4.7	30.8	34.1	19.67	18.19	1.52	0	1340	47.5	30.31
Goodwin	42.2	3.1	29.8	24.9	14.98	13.36	0.47	0	1360	54.5	27.36
Southland											
New Vale	40.5	3.1	29.9	26.4	15.25	13.66	0.34	0	1310	53.2	27.08
Ohai	18.3	4.3	34.4	43.0	24.11	22.77	0.28	0	1190	44.4	31.12
Waituna	39.6	5.5	31.0	23.9	14.53	12.96	0.58	0	1200	56.5	26.47

Table 3.4: Analysis of New Zealand industrial coals (Source: Coal Association of New Zealand, 2004)

Proximate analysis

This is the most commonly used analysis for general coal characterisation and determines the proportion by weight of moisture, volatile matter, fixed carbon and ash.

The analysis is a convenient, empirical procedure requiring the standardisation of methods and, especially for low-rank coals, the standardisation of moisture determination. Figure 3.3 shows the relationship of proximate analysis determination to coal composition.

Moisture

Moisture content is measured as the loss of water from coal on heating to 105°C. Since the moisture contents of coals change with changing conditions of temperature and humidity, and because the moisture content measured is the basis for expressing other properties, including specific energy, the treatment a coal receives between being removed from the ground and being analysed is critical. Without standardised procedures for moisture determination, systematic comparison of coals for scientific and commercial purposes is not possible, and classifications based on moisture content (e.g. ASTM) cannot be used. Since 1959 coals analysed by what is now CRL Energy Ltd are air-dried at 20°C and 70% relative humidity before analysis.

A confusing array of terms is used to describe the nature of the moisture contained in a coal and the moisture actually measured by analysis. The most important of these are:

- inherent moisture, which is that contained in the coal substance at 100% relative humidity and is roughly

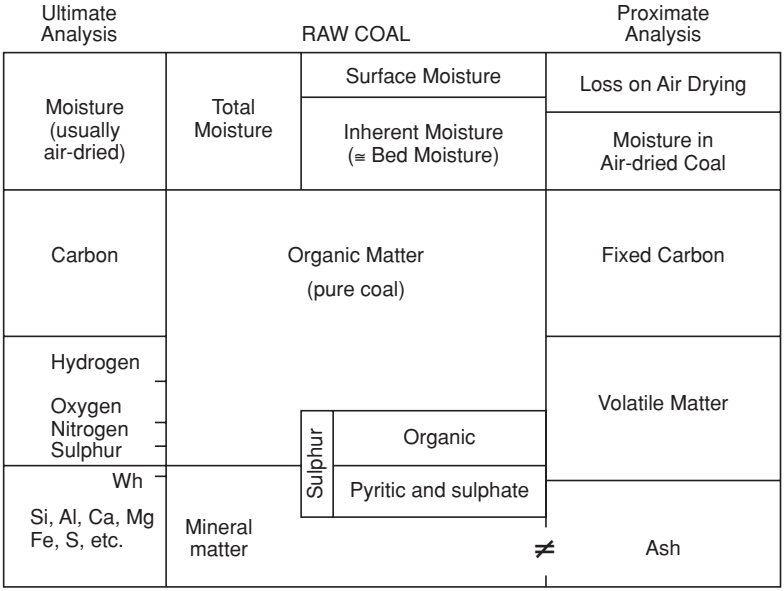

Figure 3.3. Relationship of Ultimate and Proximate analysis to raw coal composition

equivalent to the natural bed moisture required for ASTM classification

- free or surface moisture that is adhering to the coal particles in excess of inherent moisture.

Lignites may contain up to 65% inherent moisture, which starts to be lost very quickly on exposure to air and cannot all be reinstated, so that sampling procedures for low-rank, high-moisture coals are very important. On the other hand, high-rank bituminous coals have inherent moisture contents as low as 1% or 2%, and their total moisture content is likely to increase after mining by an increase in surface moisture, and, unlike low-rank coals, their inherent moisture content may increase slightly with weathering.

Volatile matter

Determination of volatile matter is by an empirical weight loss method involving heating the coal to 900°C. Accurate measurement for comparative purposes requires close adherence to exact specifications. Volatile matter as such does not occur in coal, but is composed of the products of thermal decomposition formed during heating.

Fixed carbon

This is obtained by the difference of moisture, ash and volatile matter from 100. The determination is not equivalent to carbon in the ultimate analysis, but is a measure of the solid combustible material left after moisture and volatiles have been expelled.

Ash

As measured by proximate analysis, ash is the non-combustible residue remaining after burning of the coal sample. Ash does not occur as such in coal, but is formed during the combustion process from small amounts of mineral matter inherent in the vegetable material of the coal substance, and more importantly from adventitious minerals such as clays and quartz in detrital material introduced during peat accumulation.

New Zealand coals have generally low ash contents by world standards, often around 5%. A few coals, such as some near Westport, have ash contents as low as 0.1% or less.

Miscellaneous analyses

As well as those listed above, there are several other tests, including Ash Fusion Temperature, Hardgrove Grindability Index, ssh constituents and Gieseler Plastometer.

Specific Energy (calorific value)

The heating value of coal is principally determined by the combustion of the carbon and hydrogen of the organic material; the combustion of sulphur also contributes. This is one of the key measurements for coal classification and utilisation.

Forms of sulphur

Sulphur in coals is present in three distinct forms: pyritic sulphur, sulphate sulphur, and organic sulphur. A distinguishing feature of New Zealand coals, in comparison with overseas coals, is the high proportion of organic sulphur.

Distinction between the forms of sulphur is important. In the ASTM classification system, the adjustment for mineral matter content in the coal material so as to determine the pure coal composition assumes that all sulphur is pyrite. New Zealand coals also have a very large range

of sulphur contents, which can have important implications for utilisation.

Crucible Swelling Number

Crucible Swelling Number is an empirical measure of the increase in volume of a coal when it is heated without restriction under specific conditions. It is associated with the plastic properties of coal and is principally determined by coal rank, but is significantly affected by coal type.

The test is used to evaluate coking potential as well as to predict the behaviour of coal in some types of combustion equipment. In New Zealand, only West Coast bituminous coals show swelling properties.

CO_2 Emission Factors

CO_2 emission factors refer to the amounts of CO_2 that are released in to the atmosphere when fossil fuels are burned. They are expressed either in terms of tonnes CO_2/TJ of fuel burned, or tonnes carbon/TJ (where the carbon refers to the carbon content of the CO_2 emissions).

Typical values for CO_2 emissions for New Zealand coals are shown in Table 3.5.

In general, this Handbook presents CO_2 emission factors only, i.e. the incorporation of emissions such as methane and nitrous oxides into a $CO_{2\text{-}e}$ factor is generally not presented here.

Solid Fuel type	Emission Factor	
	tC/TJ	tCO_2/TJ
Bituminous	24.2	88.8
Sub-bituminous	24.9	91.2
Lignite	26.0	95.2

Source: New Zealand's Greenhouse Gas Inventory 1990 – 2002, Ministry for the Environment

Table 3.5: Typical values for CO_2 emission factors for New Zealand coals

Other coal-based solid fuels

Coke is produced by heating bituminous coals in the absence or near absence of air. As the coal is heated it melts for a brief time at temperatures just above 400˚C, swells, then resolidifies as the temperature rises above 450˚C. During the melting/resolidification process, the coal undergoes structural change resulting in a solid material having larger pores and thicker wall structure, which is high in carbon and low in moisture and volatile matter.

Metallurgical coke is produced in the same way as coke, but at a higher temperature resulting in a harder, stronger substance. It is used in the iron and steel industry, both as a chemical agent and a source of energy.

Char is produced by low temperature distillation of non-bituminous coals that do not melt and resolidify; the resulting material retains the finer pore structure of the original coal.

Typical calorific values for coke and char are given in Table 3.6.

Fuel Type	GCV MJ/kg	NCV MJ/kg
Coke (8%-12% moisture)	27.9	27.5
Metallurgical coke	29.7	29.5
Char	29.0	28.2

Source: New Zealand Energy Information Handbook, 2nd Edition, 1993.

Table 3.6: Typical calorific values of coal-based solid fuels

4 Natural Gas

Character of the resource

Natural gas occurs in underground accumulations often in association with crude petroleum or condensate. It consists mainly of methane, but may also contain substantial quantities of ethane, propane, butane, other longer chain hydrocarbons, and trace quantities of unsaturated hydrocarbons (ethylene, propylene, etc.).

It is not uncommon, in some parts of the world, for these hydrocarbon components of natural gas to be associated with significant amounts of carbon dioxide, nitrogen and hydrogen sulphide gases. For example, some Russian and Canadian sources of natural gas have more than 70% hydrogen sulphide (by volume). In New Zealand, raw Kapuni natural gas contains approximately 43% carbon dioxide (by volume).

Gas treatment

Not all wellhead gas streams require treatment. Dry gas consists mainly of methane and ethane, but wet gas can contain substantial amounts of the longer chain hydrocarbons that can be condensed to form various natural gas liquids. The typical sequence of processes is summarised schematically in Figure 4.1.

Firstly, using a chilling process, the gas and liquid phases are separated. The heavier products are subsequently further separated into two distinct fractions – one being the stabilised condensate, and the other containing the lighter hydrocarbon components, plus CO_2 and nitrogen. Subsequent stages involve dehydration

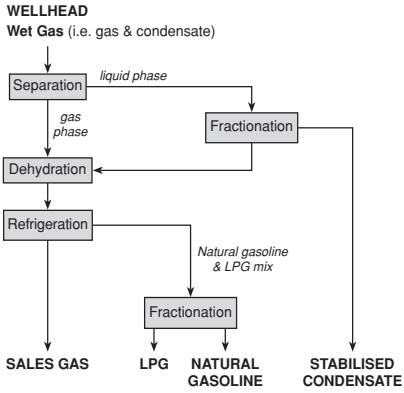

Figure 4.1: Typical treatment sequence (Gas/condensate field)

and refrigeration in order to separate natural gasoline and LPG from the sales gas stream.

Sales gas streams contain C_1 to C_6+ hydrocarbons as well as nitrogen and CO_2. On the other hand, essentially no nitrogen, CO_2 or methane, and very little ethane, are contained in any of the liquid streams. Fluctuations in the composition of the gas being processed mean that sales gas streams are usually controlled according to the Wobbe Index specification of NZS 5552:1999 *Specification for Reticulated Natural Gas*. The allowable Wobbe range makes it possible to accommodate more LPG in the sales gas streams when prior separation creates a surplus of LPG.

Fuel components of natural gas

The energy content of natural gas fuels is derived from that of its hydrocarbon components, which are summarised in Tables 4.1 and 4.2.

Component	Liquid density[1] kg/m^3	Gas density[1] kg/m^3	GCV[2] MJ/kg	NCV[2] MJ/kg
Methane	300.0[3]	0.678	55.6	50.1
Ethane	356.6[4]	1.272	51.9	47.5
Propane	506.7[4]	1.865	50.4	46.4
n-Butane	583.1[4]	2.458	49.5	45.7
iso-Butane	562.1[4]	2.458	49.4	45.6
n-Pentane	629.9	3.052	49.0	45.4
iso- Pentane	623.3	3.052	48.9	45.3
n-Hexane	662.7	3.644	48.7	45.1
n-Heptane	686.9	4.237	48.5	45.0
n-Octane	705.6	4.831	48.3	44.8
n-Nonane	720.6	5.426	48.1	44.7
n-Decane	732.8	6.017	48.0	44.6

(1) @ 15˚C and 101.325 kPa(abs) pressure; (2) @ 15˚C and constant pressure;
(3) Apparent value @ 15˚C; (4) Saturation pressure @ 15˚C

Table 4.1: Typical data for fuel components of natural gas – mass basis. (Source: Gas Processors Suppliers Association, SI Engineering Data Book)

Component	Relative density[1] water = 1	Relative density[1] air = 1	GCV[2] MJ/m^3	NCV[2] MJ/m^3
Methane	(0.3)[3]	0.554	37.7	34.0
Ethane	0.358[4]	1.038	66.0	60.4
Propane	0.508[4]	1.523	94.0	86.5
n-Butane	0.585[4]	2.007	121.8	112.5
iso-Butane	0.564[4]	2.007	121.4	112.1
n-Petane	0.632	2.491	149.7	138.5
iso- Pentane	0.625	2.491	149.3	138.1
n-Hexane	0.664	2.975	177.6	164.5
n-Heptane	0.689	3.460	205.4	190.5
n-Octane	0.707	3.944	233.3	216.5
n-Nonane	0.722	4.428	261.2	242.5
n-Decane	0.735	4.913	289.1	268.6

(1) @ 15˚C and 101.325 kPa(abs) pressure; (2) @ 15˚C and constant pressure;
(3) Apparent value @ 15˚C; (4) Saturation pressure @ 15˚C

Table 4.2: Typical data for fuel components of natural gas – volume basis. (Source: Gas Processors Suppliers Association, SI Engineering Data Book)

New Zealand resources

Indigenous natural gas production is currently all sourced from the Taranaki region. Since the inception of natural gas production in 1970 from Kapuni and from Maui in 1979, there have been numerous oil/condensate/gas fields brought into production. While Maui and Kapuni are

still the largest individual producers, there is a growing diversification of the production base including McKee/ Mangahewa, Tariki/Ahuroa and Rimu/Kauri with Pohokura having produced its first gas in 2006 and Kupe planned to begin production in 2009.

Several other fields have been drilled in recent times and show reserves potential, but further exploration activity is required to prove the reserves and the ability to flow the hydrocarbons from the reservoirs.

Typically, New Zealand's natural gases contain 5%-10% ethane, 3%-5% propane and yet smaller proportions of longer chain hydrocarbons. Of the principal natural gas sources raw Kapuni gas has an unusually high carbon dioxide level – approximately 43% by volume. When used as a chemical feedstock for the manufacture of methanol, the carbon dioxide is a useful constituent and can be left in, or blended into, the process feedstock up to about 19%-20% CO_2 by volume. However CO_2 has no useful energy content.

When natural gas is to be used in the general retail market carbon dioxide must be reduced to such a level that the natural gas complies with the Wobbe Number (and other parameters), specified in NZS 5442:1999 *Specification for Reticulated Natural Gas*. This would generally entail the carbon dioxide content being reduced to less than 8%, depending on the level of other gas constituents.

Location of major facilities

The on-shore production fields, the production station for Maui gas at Oaonui, and the three major petrochemical plants are all located in close proximity to each other, as shown in Figure 4.2.

Natural gas distribution

Without any link across Cook Strait, natural gas can only be reticulated by pipeline around the North Island. An overview of the existing distribution network is given in Figure 4.3.

Overview of natural gas sales streams

The consumption of natural gas in New Zealand can be categorised into four principal uses – electricity generation, petrochemicals manufacture in the Taranaki region, major industrial users and reticulation to domestic and commercial consumers around the North Island.

In the current market gas from any field is likely to end up in any of the above markets. With the advent of open access on most pipeline systems, most sources of natural gas can be transported, by one contractual means or another, to almost any market point of demand. Several of the key gas market players are also involved in more than one market segment. All natural gas sources are interchangeable as they must all meet the requirements of NZS 5442:1999 if they are to be transported in an open access pipeline.

Liquefied Petroleum Gas (LPG)

Liquefied Petroleum Gas (LPG) is a mixture predominantly of commercial butane and commercial propane. It will therefore contain variable but very small amounts of other closely related hydrocarbons. LPG is stored under pressure in its liquid phase at about 600 kPa depending upon ambient temperatures and product mix. Its composition is determined by production parameters but is typically 60% propane and 40% butane on a volumetric basis and generally

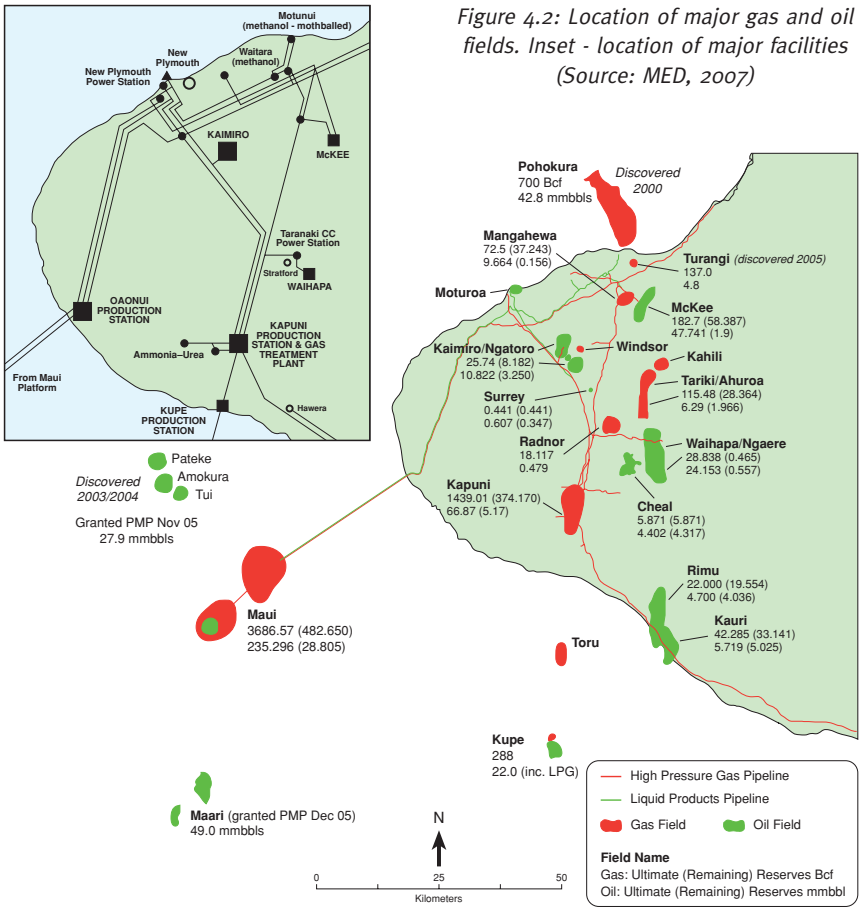

Figure 4.2: Location of major gas and oil fields. Inset - location of major facilities (Source: MED, 2007)

described as Mix. Higher propane content LPG is described as propane enriched product. Variations are permitted and are specified in NZS 5435:1996.

NZ produced LPG is a by-product of the Natural Gas stream and is treated and shipped from Taranaki to Auckland (Manukau), Christchurch, and Dunedin ports. Product is also sold on the international market and shipped offshore, mainly to the Pacific Islands. Internal distribution within NZ is essentially by road tanker, with a minor volume by rail. It is loaded by mass (tonnes) via a weighbridge into road tankers, but delivered into storage at customer sites by metered volume (litres). The principal distributor is the industry owned Liquigas, with large bulk storage depots adjacent to the above ports and from which the wholesalers draw much of their product. In the NI a large volume of product is delivered directly from the Taranaki fields by road tanker.

LPG is typically sold on a mass basis in cylinders to leisure, domestic, and

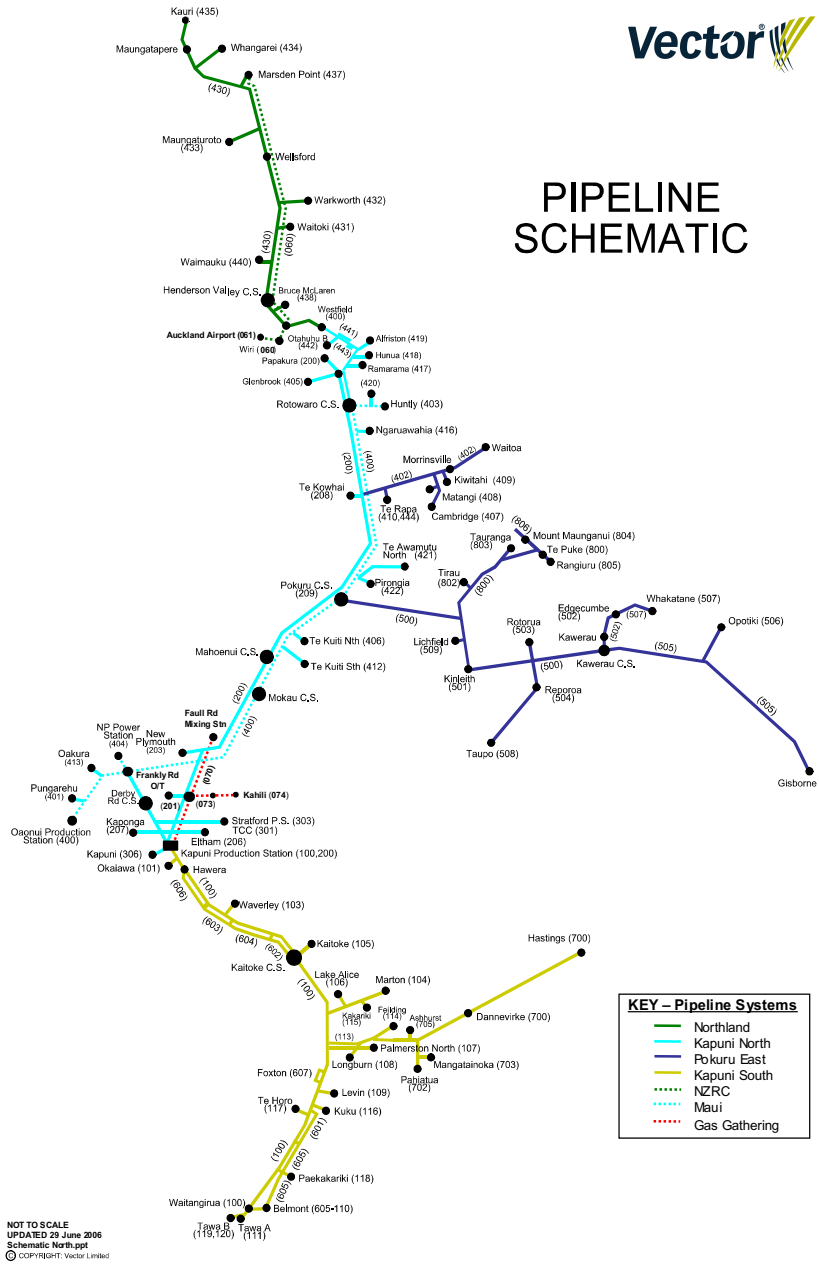

Figure 4.3: Existing natural gas high pressure gas transmission system (Source: Vector)

industrial users (kg), on a volume basis into bulk storage tanks (litres), and by energy content to reticulated users (GJ, MJ or kW)[1]. With the gradual run-down of Maui, LPG production has slowly diminished from this field. However other Taranaki fields are continuing to produce (e.g., Kapuni, Waihapa etc.) and by 2009 substantial quantities of LPG become available from the Kupe offshore field. While no decision had been made at the time of publication, the Pohokura field has the potential to produce LPG.

Meanwhile LPG with a high propane content is shipped from the East Coast of Australia, mainly into the South Island, to maintain NZ's continuing strong growth in the use of this fuel and to accommodate the winter heating peak demand. To date, LPG accounts for a very significant 9 petajoules of NZ's energy requirements.

LPG is used in many diverse applications, e.g. automotive (forklifts, taxis etc.), industrial process plants, large heating and boiler loads, dryers, laundries, bakeries, the hospitality industry, leisure, commercial and domestic users. It is sold by wholesalers direct, mainly to the larger end users, and through a wide network of service stations and agencies throughout the country. Butane is supplied in un-odorised form as an aerosol propellant, and is available in the NI in odorised form for specific customer applications.

There are substantial reticulated networks in place in Christchurch, Queenstown, Wanaka and several other smaller towns mainly in the SI because Natural Gas is unavailable there. These networks supply vaporized LPG at around 70 kPa mains pressure to a wide range of end users including recently developed residential subdivisions.

1 Sales to reticulated network users are controlled under the Gas Act 1992, Gas Regulations 1993, and measured by a gas measurement system (gas meter) within specified margins of error, reference NZS 5259:2004

Product	Liquid Specific Gravity(1, 2)	GCV		NCV	
		MJ/kg	MJ/l (3)	MJ/kg	MJ/l (3)
Commercial propane(4)	0.508	50.4	25.6	46.3	23.5
Commercial butane(4)	0.573	49.5	28.4	45.8	26.2
LPG	0.530	50.0	26.5	46.1	24.4

(1) At 15˚C; ±0.010; (2) Assuming negligible volume changes on mixing; (3) Liquid volume;
(4) Calorific values ±0.1 MJ/kg, ±0.5 MJ/l

Table 4.3: Typical energy data for LPG and component gases. (Source: NZS 5435, 1996 "Specifications for Liquefied Petroleum Gas")

Product	C content (% mass)	CO_2 emission factor	
		tCO_2/TJ	tC/TJ
Propane	82.0	59.6	16.3
Butane	83.0	61.4	16.8
LPG	82.4	60.4	16.5

Table 4.4: Typical values of CO_2 emission factors for LPG and component gases

5 Petroleum

Character of the resource

Crude petroleum is a naturally occurring flammable liquid extracted from mineral deposits – literally 'rock oil'. It consists mainly of a complex mixture of hydrocarbons: more than 90% by weight being carbon (C) and hydrogen (H), with the remainder made up of sulphur (S), oxygen (O), nitrogen (N), and various metals. Some crude oils can be burnt directly, but most are sent to refineries for processing. Natural gas liquids or condensates are made up of the longer chain and more complex hydrocarbons in crude natural gas streams. They are extracted from the wet gas stream at the wellhead or at gasoline absorption plants.

New Zealand resources

New Zealand has a number of discovered oil and condensate reservoirs in the Taranaki region. Main production sources for a number of years are the Maui, Kapuni and McKee fields.

In 2006 and 2007, significant production, by New Zealand standards, began at the Pohokura and Tui fields, respectively. The imminent development of the Kupe, Maari and Cheal fields attests to the prospectivity of the Taranaki theatre for oil and gas.

Technical infrastructure

New Zealand's petroleum needs are provided from indigenous resources and imports of crude oil and refined petroleum products. New Zealand is served by one oil refinery, located at Marsden Point, that can produce all types of refined petroleum product required in this country with the exception of aviation gasoline, light kerosene and lubricating oils.

Distribution of petroleum products from Marsden Point takes place via coastal tankers to the main ports around the country, via a truck loading facility adjacent to the refinery for Northland distribution, or via a pipeline (approximately 50%) to Wiri, in South Auckland. Road tankers distribute products from wholesaler storage tanks to retailers and bulk customers.

Product density

Petroleum products differ in both density and energy content. Liquid densities are usually expressed in terms of specific gravity. In the international petroleum industry, an alternative measure is API (American Petroleum Institute) gravity (for details see Section 16 on conversion factors). The lightest petroleum products are about half as heavy as water, while the heaviest are slightly heavier than water. There can be significant differences even within various categories of product as indicated in Figure 5.1.

Energy and product density

The energy content of both crude petroleum and its refined products is closely related to their specific gravity, as illustrated in Figure 5.2.

Energy content of petroleum commodities

Data on the energy content of petroleum commodities are listed under several categories:

- crude feedstocks to the refinery;

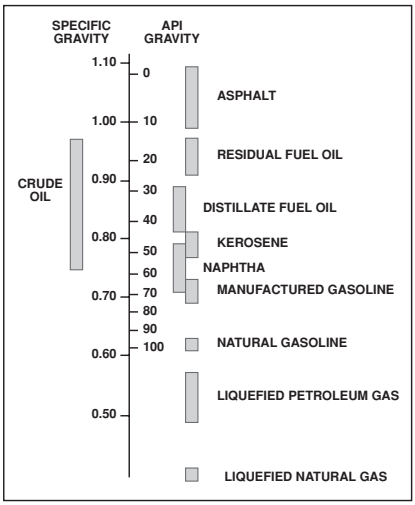

Figure 5.1: Specific gravity & API gravity (Source: Guyol)

- stocks for blending with refinery products; and
- refined products (ex-refinery or imported).

These data, comprising specific gravity, gross and net calorific value, and sulphur content are presented in Tables 5.1 to 5.3.

Variations in the energy content of fuels in particular categories are usually disregarded and a single 'typical' value applied to all products within the category. Petroleum industry sources indicate that ranges of energy content are not normally specified except in the case of aviation fuels. Specific gravity is measured for each shipment and will normally vary by no more than ±0.01.

Refined product fractions

The process of refining crude petroleum essentially involves breaking up large complex hydrocarbon molecules into smaller, simpler molecules that are separated into the different product fractions by distillation and reforming processes. Although the bulk of product is for transport and heating fuel use, some refineries also produce non-fuel products that have a significant energy content. Among them are lubricants,

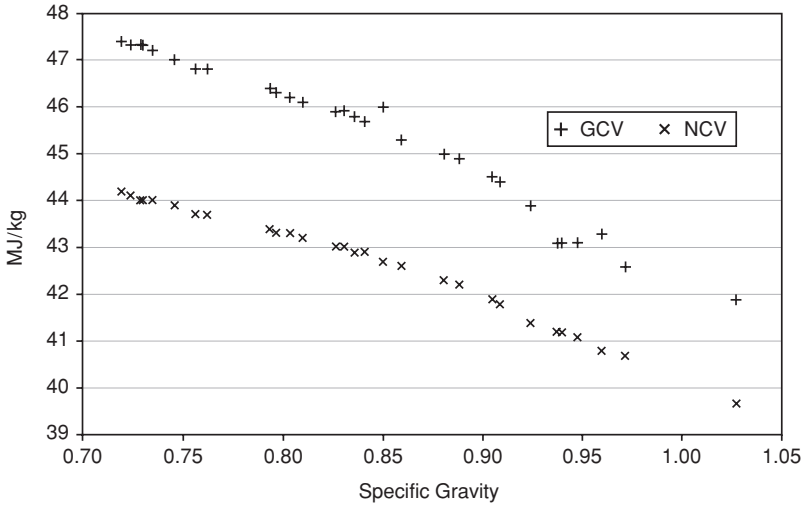

Figure 5.2: Energy content and product density

Feedstock	Specific Gravity[1]	GCV		NCV		S
		MJ/kg	MJ/l	MJ/kg	MJ/l	% mass
Al Shaheen	0.87	44.4	38.6	41.7	36.3	2.49
Arabian extra light crude	0.83	45.5	37.7	42.6	35.4	1.09
Champion	0.90	44.7	40.3	42.1	37.9	0.15
Kapuni condensate	0.76	46.8	35.6	43.7	33.2	0.04
Khafji	0.89	43.9	39.1	41.3	36.8	2.94
Low sulphur residue	0.91	44.4	40.4	41.8	38.0	0.16
Lower Zakum	0.83	45.5	37.8	42.7	35.4	1.02
Masila	0.87	45.0	39.2	42.3	36.8	0.62
Maui condensate	0.75	47.0	35.1	43.9	32.7	0.01
McKee Blend	0.82	46.0	37.7	43.1	35.3	0.08
Miri light crude	0.84	45.7	38.5	43.1	36.3	0.08
Murban	0.83	45.9	37.9	43.0	35.5	0.80
Pohokura	0.79	46.4	36.7	43.4	34.3	0.04
Qatar Land	0.82	45.6	37.4	42.7	35.0	1.22
Qatar Marine	0.86	44.7	38.4	42.0	36.1	2.02
Ratawi	0.91	43.4	39.5	40.9	37.2	3.59
Umm Shaif	0.84	45.7	38.4	42.9	36.0	1.31
Varanus Light	0.78	46.6	36.3	43.5	34.0	0.02
West Seno	0.83	45.8	38.0	43.0	35.7	0.12
Woollybutt	0.78	46.6	36.3	43.5	34.0	0.01

1 at 15˚C and atmospheric pressure

Table 5.1: Typical values for crude feedstocks to the Marsden Point refinery (Source: The NZ Refining Co Ltd)

Blendstock	Specific Gravity	GCV		NCV		S
		MJ/kg	MJ/l	MJ/kg	MJ/l	% mass
Light cycle oil	0.91	44.5	40.5	41.5	38.2	0.3
Cracked spirit	0.72	47.3	34.1	44.1	31.8	0.025
Premium Unleaded Petrol	0.73	47.2	34.5	44.0	32.2	0.01

Table 5.2: Typical values for blendstock (Source: The NZ Refining Co Ltd)

including oils and greases, bitumen (or asphalt), paraffin wax, white spirits and other products used as solvents, and petroleum coke that is rich in carbon and used in the manufacture of carbon electrodes. How these different product fractions are related to end use is summarised in Table 5.4.

In the mid 1980s the Marsden Point refinery was modernised and expanded to incorporate a hydrocracker unit, allowing larger quantities of heavier feedstocks to be processed. As a result of changes to petroleum product specifications a large hydrodesulphuriser for diesel and a benzene removal unit for petrol were added to the refinery in 2005. As of 2007, a significant ($180m) 'Future Fuels' upgrade and expansion is underway.

Refined Product	Specific Gravity[1]	GCV		NCV		Max. S
		MJ/kg	MJ/l	MJ/kg	MJ/l	% mass
Premium petrol	0.73	47.2	34.5	44.0	32.2	0.005
Regular petrol	0.73	47.2	34.5	44.0	32.2	0.005
Kerosene / Jet A1	0.79	46.4	36.6	43.4	34.3	0.2
Premium kerosene	0.81	46.1	37.4	43.2	35.0	0.02
Diesel (AGO)	0.83	45.9	38.1	43.0	35.7	0.005[(2)]
Marine diesel	0.84	45.6	38.3	42.8	35.9	0.3
Light fuel oil	0.9	44.1	39.7	41.5	37.3	2
Heavy fuel oil	0.95	42.8	40.6	40.4	38.4	3.5
Bunker fuel oil	0.96	42.4	40.7	40.1	38.5	4
Export fuel oil	0.94	42.9	40.4	40.5	38.1	3.5
Bitumen	1.03	41.9	43.1	39.7	40.8	n/a

1 at 15˚C and atmospheric pressure
2 From January 1 2009 maximum sulphur decreases to 0.001%

Table 5.3: Typical values for refined products (Source: The NZ Refining Co Ltd)

Petroleum fraction	C atoms per molecule	Approx. boiling range °C	Major uses
Gasoline	5 - 12	30 - 200	Gasoline engines
Kerosene	10 - 15	180 - 275	Diesel & jet engines
Fuel (or gas) oil	15 - 22	260 - 345	Heating
Lubricating oil	20 - 30	340 - 400	Lubrication
Residue	> 30 +	> 400 +	Heating, asphalt, etc

Table 5.4: Characteristics of principal petroleum fractions (Source: Glasstone, 1982)

CO_2 emission factors for petroleum-based fuels

CO_2 emission factors for petroleum-based fuels are reported in Table 5.5. These are based on IPCC emission factors.

Terminology

Aviation Fuels are of two types — the gasoline type, which is somewhat more volatile than kerosene and is marketed as Avgas; and the kerosene type, which is sometimes called Avtur or Jet Fuels.

Bitumen (also called asphalt or tar), is the brown or black viscous residue from the vacuum distillation of crude oil. It also occurs naturally in asphalt 'lakes' and tar sands. It consists of high molecular weight hydrocarbons and minor amounts of sulfur and nitrogen compounds and is used for road building and roofing.

Cetane Number is a parameter that indicates the ignition qualities of a diesel fuel. A high cetane number represents a short ignition delay time, i.e. delay between injection of the fuel into the cylinder and ignition.

Distillate Fuel Oil includes a variety of intermediate products, such as diesel oil, gas oil and light heating oil. The term 'diesel' is often used colloquially as a generic term for gas oil (automotive

Fuel / Fuel type	GCV	C content	CO_2 emission factor	
	TJ/kt	% mass	tCO_2/TJ	tC/TJ
Gasoline Fuels				
Premium petrol	47.2	86.0	67.0	18.3
Regular petrol	47.2	86.0	66.2	18.1
Aviation Fuels				
Premium kerosene	46.1	87.0	68.7	18.7
Kerosine/Jet-A1	46.4	87.0	68.1	18.6
Avgas	47.3	85.0	65.0	17.7
Diesel Fuels				
Automotive gas oil	45.9	86.0	69.5	18.9
Marine diesel oil	45.6	86.0	73.5	20.1
Blended heating oil	46.2	86.0	68.3	18.6
Fuel Oils				
Light fuel oil	44.1	88.0	72.0	19.8
Power station fuel oil	44.5	88.0	72.5	19.8
Heavy fuel oil	42.8	88.0	73.5	20.1

Table 5.5: Typical values of CO_2 emission factors for petroleum-based fuels

diesel) and marine diesel. Diesel oil is used mainly in compression-ignition internal combustion engines. Distillate fuel oils are occasionally used for thermal electricity generation. In these cases, the product is described generally as power station fuel oil (PSFO).

Petrol (Gasoline) (C_5-C_{12}) is the liquid most widely used as a fuel in internal combustion engines of the spark-ignition type. Aviation gasoline is giving way to jet fuels in most commercial and military services, but motor gasoline remains a principal fuel for road transport. In New Zealand, two types of motor gasoline are marketed – Premium Unleaded (95 or 98 octane) and Regular Unleaded (91 octane).

Kerosene is a mixture of liquid hydrocarbons, heavier than gasoline but lighter than gas oil. Apart from its applications in aviation, kerosene has been declining in importance. Its other applications include farm vehicles and domestic space heating.

Naphtha is a general term applied to various mixtures of liquid hydrocarbons with boiling points partially overlapping the ranges of gasoline and kerosene. In petroleum refining, the naphtha fraction may be converted into other more specific fuels by a process known as reforming. In industry, naphthas are used mainly as solvents and cleaning agents and can be a major component of fertiliser for agriculture.

Octane Number is a parameter that relates combustion efficiency to compression ratio for gasoline fuels.

Petroleum Coke is the solid carbonaceous material remaining after

severe thermal decomposition of the residual oils from petroleum distillation. Petroleum coke can serve as a fuel, but it has important industrial non-fuel uses, such as the manufacture of carbon anodes for use in aluminium smelting.

Residual Fuel Oil is the residue of petroleum refining. It is sometimes subclassified into the categories of Light and Heavy Fuel Oil and is used mainly as an industrial boiler fuel, including power station fuel oil (PSFO), and for marine bunkering purposes.

6 Geothermal

Character of the resource

Geothermal energy is a globally vast renewable energy resource consisting of thermal energy, or heat, stored beneath the earth's surface or discharged from it as hot water and steam. This heat is brought to the surface by thermal conduction and by near-surface intrusions of molten magma originating from great depth.

The resulting heat flux is concentrated along the tectonic plate boundaries, locations of elevated heat flow, and seismic and volcanic activity, the latter transporting molten magma to depths of 5-20 km, where it slowly cools and heats the surrounding rock. Where sufficient permeability (due to the presence of fractures) and/or porosity exist in this hot rock, and where water is naturally available, it can circulate down and through the hot rock creating large reservoirs of hot fluid (water and/or steam). These geothermal, or hydrothermal, systems typically exhibit surface areas of several square kilometres over which are generally distributed various thermal features such as hot springs, geysers, mudpools and fumaroles.

In hydrothermal systems, the energy (heat) in the reservoir is distributed between the hot rock and the hot fluid present in its fractures and pores. To extract the geothermal heat it is necessary to produce the hot water and steam by drilling wells into the reservoirs. Typically, commercial geothermal resources require drilling to depths of less than 3 km. The hot fluids generally discharge spontaneously from the wells at sustainable flow rates of up to hundreds of tonnes per hour for many years. Most hydrothermal reservoirs are liquid-dominated, i.e. the wells produce mainly hot water; though some are vapour-dominated, with steam produced.

Serious attention is now also being directed to accessing the enormous heat resources available in the hot rocks present at depths of 3-10 km, almost anywhere on earth, for electricity production. Once known as hot dry rock (HDR), because of the absence of water in the hot rock of these resources, the terminology has now changed to enhanced [or engineered] geothermal systems (EGS), because man must literally create the reservoir by enhancing permeability (by fracturing the rock) and providing the water, to access the heat.

Recent assessments of the deep heat resources for EGS development have been performed for the USA, and parts of China and India, indicating potentials of at least 100,000 MW_e in each country that can be utilised for both electricity generation and direct heat applications (such as industrial process heat, district heating, greenhouses, aquaculture and heat pumps) as co-generation options prior to reinjection of the fluid to continue the utilisation cycle. The first EGS pilot plants are expected to be installed at Soultz-sous-Forêts, France and Cooper Basin, Australia, by mid-2008.

Commercial generation of electricity generally requires reservoir temperatures in excess of about 100°C; using flash steam power plants for fluids with temperatures greater than about 180°C and binary plants for the lower temperature fluids. Developers typically aim to

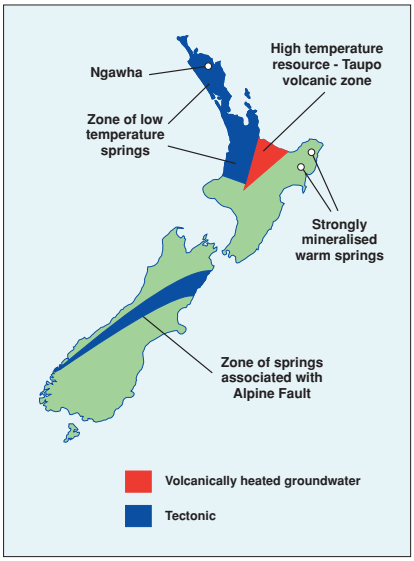

Figure 6.1: Geothermal systems in New Zealand

produce at least 5-10 MW_e from commercial wells. Most New Zealand geothermal power stations currently utilize reservoir fluids having temperatures of about 230˚C-320˚C, with some also utilising the 'waste' separated hot water discharged from the main station to generate electricity with binary generators (e.g. Wairakei has a 15 MW_e binary generator), thus increasing efficiency. Geothermal power stations in New Zealand range in size from 3.5 MW_e at Kawerau to 234 MW_e at Wairakei. The lower temperature (‹150˚C) resources can be used for direct heat applications.

In 2007 there was 523.5 MW_e of installed geothermal electricity generation capacity in New Zealand, with geothermal power stations supplying 6%-7% of baseload electricity demand (see Table 6.1).

In addition, there are a number of geothermal fields in New Zealand that are currently untapped or underdeveloped, and that could potentially be developed assuming access and consenting is achieved. Overall, geothermal energy is expected to make an even greater contribution to supplying New Zealand's increasing demand for electricity. Conservative estimates, taking account of likely consent restrictions, have indicated that more than 1,000 MW_e of new geothermal power stations could be installed (see Table 6.1). Of this, there are 255 MW_e under construction, preparing for construction, or consented. Some developers have spoken of an additional 400 MW of geothermal power stations being installed over the short- to medium-term.

Geographical distribution

Geothermal systems are found in many parts of New Zealand, in both the North and South Islands. These are shown in Figure 6.1. However, almost all the known high-grade resources are located within the Taupo Volcanic Zone, the region of surface thermal activity that stretches between Ruapehu and the Bay of Plenty. The sole exception is Ngawha located in Northland near Kaikohe.

Table 6.1 lists the high temperature geothermal systems in New Zealand (from Lawless and Lovelock, 2001), with estimates of area, temperature and electricity generating capacity. Most of these resources have been drilled with exploratory wells. Regulatory status and environmental constraints have been ignored for the purpose of this table.

Regulatory status

The use of geothermal energy falls under the Resource Management Act, administered by the Regional Councils. New

Field	Resource Area km^2	Resource Temperature °C	Generating Capacity MW_e	Current Installed MW_e	Additional Capacity[1] MW_e
	min - max	*min - max*	*min - max*		
Atiamuri	0 - 5	190 - 240	1 - 18		0
Horohoro	0 - 5	180 - 240	1 - 15		5
Kawerau	25 - 40	260 - 280	350 - 570	17.5	155
Ketetahi	10 - 30	230 - 260	70 - 150		0
Mangakino	0 - 10	200 - 250	20 - 70		47
Mokai	5 - 16	260 - 290	95 - 220	111	32
Ngatamariki	8 - 12	250 - 270	90 - 160		120
Ngawha	10 - 25	220 - 260	50 - 120	10	25
Ohaaki	6 - 12	260 - 280	100 - 170	116	52
Orakei-Korako	8 - 12	240 - 260	90 - 135		0
Reporoa	0 - 12	220 - 240	20 - 65		0
Rotokawa	12 - 20	260 - 290	230 - 400	35	256
Rotoma	4 - 6	220 - 245	28 - 46		10
Rotorua[2]	2 - 8	220 - 250	25 - 55		2
Tauhara	7 - 35	240 - 270	200 - 500		158
Te Kopia	6 - 12	230 - 250	75 - 120		0
Tikitere-Taheke[3]	15 - 40	220 - 260	160 - 350		240
Tokaanu	10 - 30	250 - 270	130 - 300		99
Waimangu	9 - 30	250 - 270	180 - 420		0
Waiotapu[4]	15 - 30	260 - 280	250 - 450		0
Wairakei	15 - 30	250 - 265	380 - 670	234	47
Means & Totals:	**8 - 20**	**235 - 260**	**2550 - 5000**	**523.5**	**1248**

1 Estimated available additional capacity considering consent restrictions
2 Excludes Lake Rotorua
3 Excludes Lake Rotoiti
4 Includes Waikite

Table 6.1: Estimated parameters for high temperature geothermal systems. Minimum and maximum generating capacities are taken from the 10th and 90th percentiles. (Source: Geothermal Association of New Zealand/NZGA 1)

Zealand's geothermal systems are classified for development or protection by regional authorities. A number of potentially commercial major geothermal systems in the Taupo Volcanic Zone are protected from large-scale commercial development, most notably Rotorua, Waiotapu, Waimangu and Orakeikorako.

Current use

Currently, commercial-scale electricity generation is carried out at six locations: Wairakei (234 MW_e installed, 3 plants); Ohaaki (116 MW_e); Kawerau (17.5 MW_e, mostly off-grid); Rotokawa (35 MW_e); Mokai (111 MW_e); and Ngawha (10 MW_e). All of these geothermal resources are predominantly liquid-dominated.

Direct use of geothermal heat (i.e. non-electricity generation) is roughly equal to the electricity generation (i.e. about 10,000 TJ/y) in terms of consumer energy

use (White, 2006). It is used mainly in the Bay of Plenty and Waikato areas – at the Kawerau mills for industrial processing (for paper and timber drying), at Mokai for greenhouse heating, at Wairakei for prawn farming, at Ohaaki for timber drying and at Rotorua, Taupo and Tauranga for space heating. Tourist spa developments are numerous, including some in the South Island. There is also a long history of use by Maori for cooking, washing, bathing and therapeutic applications.

Energy content

The energy of a geothermal system is contained in the hot fluid and rock. The heat is utilised by extracting the fluid with geothermal wells. Well performance is determined by flowrate, energy content (enthalpy) and pressure. The discharge enthalpy is generally obtained by measuring the flow of steam and water and using the specific enthalpy of these components (normally expressed as kiloJoules per kg) to obtain the enthalpy of the total flow. The conversion efficiencies for the use of geothermal fluid are about 10% for electricity generation and 50% for direct use.

Field enthalpy is defined as the total heat flow from all producing wells divided by the total mass flow. This value will be determined by the reservoir temperature and the relative quantities of water and steam, with steam having a much higher specific enthalpy.

Knowing the total mass flow, enthalpy and well-head pressure, the electricity generating capacity can be calculated for the chosen power plant design. However, well outputs change with time, and assessment of the sustainable capacity is a complex issue.

Carbon dioxide emissions

Carbon dioxide is a very small component of geothermal fluids and is discharged naturally through surface thermal features. It originates from the de-gassing of the deeper magma heat sources and from the release of carbon dioxide from reservoir rock by the fluids passing through them. Geothermal production fluids therefore contain carbon dioxide; typically less than a few percent by weight. Most of the carbon dioxide remains with any steam that is separated from the production flow and is eventually released to the environment. However, carbon dioxide at a few developments is collected and used in the manufacture of carbonated beverages and for supply to greenhouses to stimulate plant growth.

In New Zealand the gas content of reservoir fluid ranges from <0.1% at Wairakei to about 2% at Ohaaki. Overall, the gas emissions are significantly less than equivalent generation using fossil fuels, averaging only about 5% of the emissions from equivalent sized fossil fuel plants, though for the exceptional higher-gas systems emissions can be comparable to gas-fired combined cycle plants (NZGA 2). The average carbon dioxide emission from New Zealand geothermal developments is about 100 g/kWh, compared to 400 g/kWh for gas-fired combined cycle plants (*ibid.*).

Other constituents

Geothermal fluid contains other constituents apart from steam, water and carbon dioxide. The brine contains dissolved solids with major constituents being sodium, chloride, potassium and silica. Total dissolved solids range from about 0.1% to 1% in New Zealand geothermal

waters. Environmentally harmful constituents include boron, lithium, fluoride and arsenic, although with modern geothermal projects total reinjection of the waste brine removes these hazards.

Carbon dioxide is by far the major non-condensible gas (>90%). Minor gases include hydrogen sulphide, ammonia, nitrogen, methane, hydrogen and traces of mercury.

7 Wood

Character of the resource

Wood can be used as a source of energy in a variety of ways. Combustion as a solid fuel, either as wood or wood pellets, is the focus of this section. It can also form the feedstock for conversion to other solid, liquid and gaseous fuels. Information on these energy commodities is reported elsewhere in this handbook.

As an energy resource, wood is mainly harvested from exotic plantations, as well as collected from forest industry wastes.

Wood composition

Wood fuels vary by tree type and wood material (e.g. bark, heartwood, sapwood, needles, etc.). While physical structure is not important in determining the energy value of wood materials, the chemical composition is. Wood is a composite of three basic polymers: cellulose, hemicellulose, and lignin. These are all chemical combinations of carbon, hydrogen and oxygen. In addition, wood contains extractives (such as resins and tannins), minerals and moisture. Lignin content and the level of extractives modify the basic energy value.

Wood species are generally categorised into softwoods and hardwoods. Table 7.1 gives generic data on the analysis of these main types in three formats (for the relationship between ultimate and proximate anaylsis, see Figure 3.3, p16).

Different conditions of wood

Three conditions of wood are frequently referred to. 'Green' or wet wood is freshly

Analysis	Softwoods (%)	Hardwoods (%)	Bark (%)	Straw (%)	Peat (%)
Chemical composition (dry basis)					
Cellulose	41-43	39-43	34	40	10
Hemicellulose	24-28	35	16	28	32
Lignin	28-29	20-22	34	17	44
Ultimate analysis (dry basis)					
Hydrogen	6.1	6.2			
Carbon	53.0	51.0			
Oxygen	38.8	39.9			
Sulphur	-	-			
Ash	1.7	2.5	2	7	6
Proximate analysis					
Volatiles	40.6	52.4			
Fixed carbon	12.4	12.9			
Ash	1.0	2.7			
Moisture	46.0	32.0			

Table 7.1: Typical composition values (% by mass) for softwoods and hardwoods (Source: Tillman, 1980)

cut. 'Air-dried' wood has been allowed to stand for some time until its moisture content has reduced – dry wood usually refers to an average moisture content of less than 25%. 'Oven-dried' wood has had all the moisture removed. These conditions of wood should not be confused with the different bases for measuring wood condition.

Volumetric conversion factors

In measuring volumes, several units have come into use that are peculiar to the measurement of wood, such as the cord (4ft x 4ft x 8ft=128ft^3) and the stacked cubic metre. They take into account the fact that when wood is collected together there is always a considerable voidage (volume of air in the spaces between the separate pieces of wood) associated with the total observed volume.

Conversion factors are given in Table 7.2.

Different bases for measurement

The most common basis for measuring wood mass, wood moisture or wood energy content per unit mass is the 'oven-dry' unit - i.e. per oven-dry kg, although the 'wet wood' basis is occasionally used. Density is frequently expressed as 'basic density' (oven-dry mass/green volume), or 'air-dry density' (air-dry mass/air-dry volume).

Calorific value – mass basis

It is normal practice to express the energy content per unit mass of wood as the net calorific value on an oven-dry basis. On this basis, softwoods generally have slightly higher calorific values. The difference is due to the higher lignin content of softwoods. Within these categories, there is little difference between species (5%-8% max.) unless the extractive contents are widely different. Because bark has a higher level of extractives, its calorific value is normally higher than that of wood. Typical net calorific values (MJ/kg oven-dry wood) are:

Softwoods	19.2
Hardwoods	18.2
Bark	19.7

Effect of moisture

Moisture in wood fuels markedly affects the calorific value. The reduction in gross calorific value is directly proportional to the amount of moisture present. Moisture content is usually defined on an oven-dry basis as:

> Moisture content (%) = mass of water in the wood x 100/oven dry mass of wood.

It is, however, sometimes seen on a wet wood basis. The relationship between net calorific value and wood moisture is set out in Table 7.3 for both softwoods and hardwoods. Each kilogram of water present reduces the calorific value by 2.267 MJ.

To convert to:	**m^3 solid wood**	**Cord**(1)	**Stacked m^3**
from:	*multiply by*		
m^3 solid wood	1.0	0.45	1.42
Cord	2.2	1.00	3.20
Stacked m^3	0.7	0.32	1.00

1 Cord (128 ft^3 or 3.6 m^3) is no longer a recognised measure for firewood sales

Table 7.2: Volumetric conversion factors for wood quantities

Density

Although density does not affect the fuel value of firewood on a mass basis, wood fuels are generally sold by volume and the heat content/volume is related to density. In addition, other properties such as moisture content, rate of combustion, and restoking period are related to density.

In general, the higher the density the better the fuel value of the wood. Tables 7.4 and 7.5 list typical values of density and moisture content for a range of potential firewood species.

Calorific values – volume basis

The calorific value of wood on a volume

Moisture content oven-dry basis (%)[1]	Moisture content wet wood basis (%)[2]	Softwoods MJ/kg wet	Hardwoods MJ/kg wet
0.0	0.0	19.2	18.2
10.0	9.1	17.2	16.3
11.1	10.0	17.1	16.2
20.0	16.7	15.6	14.8
25.0	20.0	14.9	14.1
30.0	23.1	14.2	13.5
40.0	28.6	13.1	12.4
42.9	30.0	12.8	12.1
50.0	33.3	12.0	11.4
60.0	37.5	11.2	10.5
66.7	40.0	10.6	10.0
70.0	41.2	10.4	9.8
80.0	44.4	9.7	9.1
90.0	47.4	9.0	8.5
100.0	50.0	8.5	8.0
120.0	54.5	7.5	7.0
140.0	58.3	6.7	6.3
150.0	60.0	6.3	5.9
160.0	61.5	6.0	5.6
180.0	64.3	5.4	5.0
200.0	66.7	4.9	4.6
220.0	68.8	4.4	4.1
233.3	70.0	4.2	3.9
240.0	70.6	4.1	3.8
260.0	72.2	3.7	3.4
280.0	73.7	3.4	3.1
300.0	75.0	3.1	2.9

1 Moisture content on an oven-dry basis: kg moisture/kg oven-dry wood; 2 Moisture content on a wet wood basis: kg moisture/kg wet wood [NB. Wet wood = oven-dry wood content + moisture content]

Table 7.3: Reduction in net calorific value with moisture content

Species	Common Name	Wood density		Bark density	
		kg/m^3 green[1]	kg/m^3 basic[2]	kg/m^3 green[1]	kg/m^3 basic[2]
Acacia dealbeta	Silver wattle	959	468	1036	110
A. decurrens	Green wattle	1060	560	1124	90
A. mearnsii	Black wattle	1128		1156	142
A. melanoxylon	Tasmanian blackwood wattle	889	428	1013	129
Acer pseudoplatanus	Sycamore	884	528	961	67
Albizia lophantha	Silk tree	819	353	893	133
Alnus glutinosa	European or Black alder	762	384	821	98
Casuarina cunninghamiana	River She-oak	1157	506	1000	130
C. glauca	She-oak	1105	556	1014	99
Chamaecytisus palmensis	Tree lucern	1152	619	857	86
Cupressus macrocarpa	Macrocarpa		485		
Eucalyptus botryoides	Bangalay	1087	400	1179	172
E. delegatensis	Alpine ash	1082	400	848	
E. fastigata	Brown barrel	1102	400	1030	176
E. fraxinoides	White ash	1116	442		
E. globoidea	Tasman bluegum		588		
E. microcorys	Tallow wood	1110	604		
E. muellerana	Yellow stringybark	1145	536		
E. nitens	Shining gum	1074	414	979	380
E. pilularis	Blackbutt	1130	562		
E. pyrocarpa	Pear fruited blackbutt		434		
E. regnans	Mountain ash	1076	390	973	294
E. saligna	Sydney bluegum	1068	434	1006	260
Pinus radiata	Monterey pine	1015	323	878	326
Populus candicans	Poplar		331		
Pseudotsuga taxifolia	Douglas Fir		446		
Salix alba	White willow	787	378		
S. alba x matsudana	Aokautere willow	722	330	765	334
S. matsudana	Matsudana willow	946	451	732	388
Taxodium distichum	Cypress		482		

1 Green or wet wood density = mass of green wood x100/volume of green wood;
2 Basic density = mass of oven-dry wood x100/volume of green wood

Table 7.4: Typical values of density for potential firewood species – wood content. (Source: Miller and Young, 1989)

basis is affected by the density of the wood and its moisture content. Data (MJ/m3) for potential firewood species in 'green' and 'air-dry' (25% moisture content) conditions are shown in Table 7.6. These values were calculated from the density and moisture content data of Tables 7.4 and 7.5, together with standard calorific values. The presence of significant amounts of extractives could

raise the heat content above these values.

Data for wood residues

When wood is harvested and processed, quantities of waste material are generated that still have potential fuel value. Table 7.7 summarises typical values of moisture content and net calorific value for such wood residues. Corresponding gross calorific values are estimates provided by Hennessy (1992), based on the NCV estimates and the following

Species	Common Name	Wood	Bark	
		% moisture[1]	% volume[2]	% moisture[1]
Acacia dealbeta	Silver wattle	110	9.4	119
A. decurrens	Green wattle	90	18.0	132
A. mearnsii	Black wattle	142	17.3	164
A. melanoxylon	Tasmanian blackwood wattle	112	17.8	129
Acer pseudoplatanus	Sycamore	67	8.5	79
Albizia lophantha	Silk tree	133	16.8	157
Alnus glutinosa	European or Black alder	98	16.5	87
Casuarina cunninghamiana	River She-oak	130	14.7	103
C. glauca	She-oak	99	23.4	81
Chamaecytisus palmensis	Tree lucern	86	19.0	151
Eucalyptus botryoides	Bangalay	172	17.3	375
E. delegatensis	Alpine ash	169	14.1	-
E. fastigata	Brown barrel	176	19.5	270
E. fraxinoides	White ash	153	19.7	-
E. globoidea	Tasman bluegum	-	45.9	-
E. microcorys	Tallow wood	82	17.2	-
E. muellerana	Yellow stringybark	116	40.8	-
E. nitens	Shining gum	160	18.7	158
E. pilularis	Blackbutt	94	32.0	-
E. pyrocarpa	Pear fruited blackbutt	-	21.3	-
E. regnans	Mountain ash	180	11.3	231
E. saligna	Sydney bluegum	147	21.6	287
Pinus radiata	Monterey pine	216	12.7	169
Salix alba	White willow	108	10.0	-
S. alba x matsudana	Aokautere willow	120	8.4	129
S. matsudana	Matsudana willow	109	11.4	89

1 Moisture contents are on an oven-dry basis i.e. moisture content of green wood when measured on an oven-dried basis; 2 Bark volume as a percentage of stem wood

Table 7.5: Typical values of moisture content for potential firewood species – bark content. (Source: Miller and Young, 1989)

assumptions:

(1) GCV=NCV+0.212*H*(10.01*M)+0.0008*O*(1-0.01*M)+0.0245*M, where M = % moisture, H = % hydrogen, O = % oxygen;

(2) For both softwood and bark H and O contents (dry basis) are assumed to be 6.25% and 42.9% respectively. Values for black liquor are not known. Hennesy's estimate for the GCV of oven-dried wood is 20.6MJ/kg.

Species	Common Name	Wood heat content(1)		Total heat content(2)	
		MJ/m³ green	MJ/m³ air-dry	MJ/m³ green	MJ/m³ air-dry
Acacia dealbeta	Silver wattle	7350	8250	7420	8330
A. decurrens	Green wattle	9050	9870	8880	9760
A. mearnsii	Black wattle	7100	8360	7080	8360
A. melanoxylon	Tasmanian blackwood wattle	6700	7550	6830	7710
Acer pseudoplatanus	Sycamore	8810	9310	8880	9390
Albizia lophantha	Silk tree	5360	6220	5400	6290
Alnus glutinosa	European or Black alder	6140	6770	6410	7040
Casuarina cunninghamiana	River She-oak	7720	8920	7840	8990
C. glauca	She-oak	8870	9800	9130	10010
Chamaecytisus palmensis	Tree lucern	10060	10910	9210	10080
Eucalyptus botryoides	Bangalay	5720	7050	5210	6650
E. delegatensis	Alpine ash	-	7050	-	-
E. fastigata	Brown barrel	5680	7050	5310	6710
E. fraxinoides	White ash	6510	7790	-	-
E. globoidea	Tasman bluegum	-	10370	-	-
E. microcorys	Tallow wood	9870	10650	-	-
E. muellerana	Yellow stringybark	8350	9450	-	-
E. nitens	Shining gum	6030	7300	6050	7290
E. pilularis	Blackbutt	9030	9910	-	-
E. pyrocarpa	Pear fruited blackbutt	-	7650	-	-
E. regnans	Mountain ash	5510	6880	5370	6740
E. saligna	Sydney bluegum	6450	7650	5800	7070
Pinus radiata	Monterey pine	4620	6020	4690	6050
Salix alba	White willow	5950	6660	-	-
S. alba x matsudana	Aokautere willow	5110	5820	5150	5870
S. matsudana	Matsudana willow	7090	7950	7060	7890

1 Wood heat content is the net calorific value on a volume basis;
2 Total heat content is the heat content of the whole stem including bark

Table 7.6: Typical net calorific values of potential firewood species (Source: Miller and Young, 1989)

Wood source	Moisture content		NCV	GCV
	% wet	% oven-dry	MJ/kg wet	MJ/kg wet
Forest residues	30-60	-	-	-
Fresh harvested wood	50-55	100-120	7.4 ± 25%	9.3
Bark – undried	60-70	150-230	7.0 ± 25%	9.1
Sawmill residues & fuel merchant fuelwood – undried	38-41	60-70	10.3 ± 20%	12.1
Timber merchant, building & wood container residues	23-29	30-40	13.3 ± 13%	14.9
Joinery, furniture, veneerboard residues	12-14	4-16	16.3 ± 13%	17.8
Wood pulp black liquor	50	-	8.6 ± 15%	10.5

Table 7.7: Calorific values for fuelwood and residues (MED, 2007)

Wood Pellets

Wood pellets are a clean-burning, low emission fuel. When they are burned in specially designed pellet fireplaces thermal efficiencies as high as 90% may be achieved. Wood pellets are especially suitable for home heating and may also be economic for some smaller space heating boiler applications (less than 200 kW), such as schools.

The fuel produces 10% of the emissions of typical solid fuel domestic burners and around 1% of the emissions from an open fire[1]. Unlike firewood, burnt pellets leave little residue. Storage of the fuel requires dry conditions.

Wood pellets are a relatively new fuel in the New Zealand marketplace, having only been available since 1997. Overseas, it has a history going back about 30 years and pellets are quite widely used in Europe and North America.

In New Zealand, pellets are made from shavings and sawdust from Pinus radiata. These are dried and ground into a powder, which is then compressed so that the lignin in the wood binds the powder to form the pellets. The manufacturing process is also quite low carbon.

The fuel cost of pellets is comparable to heatpumps or nightstore heaters on a c/kWh basis, and substantially less than the cost of LPG or conventional electric heaters, at 2007 prices.

Energy Content	19 MJ/kg
Specific Gravity	640 kg/m^3
Moisture Content	5.0%
Ash Content	< 0.5%

Table 7.8: Wood pellet properties

Retting

Retting is a term which refers to the process in which woody materials are soaked in water for several days or longer at normal air temperatures. This allows the chopped, moistened woody residues to partially decay through biologicial action. Partially decayed and processed cellulosic materials give a higher heating value than if the materials are simply dried. For example, dried rice straw (10 percent moisture content) has a heat value of only 7 MJ/kg, but this will increase to between 17.4 MJ/kg and 28 MJ/kg when the material has partially rotted before it is dried.

[1] www.naturesflame.co.nz

8 Energy from Waste

Character of the resource

There are several ways by which solid waste materials can be used as a source of energy. These derive from the organic content of wastes including paper, kraft, cardboard, plastic, and biomass materials such as wood residues and garden and kitchen wastes.

The most common methods of utilisation for energy are incineration to produce heat, and anaerobic digestion to produce methane, although the former has atmospheric impacts that are either costly or impossible to avoid. The use of organic wastes as feedstocks for liquid fuel production has also been explored.

Factors affecting energy content

The useful energy content of solid waste depends on the proposed method of utilisation. Incineration has the potential to harness the energy of combustion of all carbon and hydrogen in the waste materials. Methane production will tap only those components that can be decomposed by biological action, thus excluding most plastics.

The principal factors affecting the energy content of solid wastes are waste composition and moisture content.

Nature of the data

Up-to-date data on the composition of aggregate municipal solid wastes (MSW) and associated estimates of calorific value are not available. Furthermore, with the rising concern about volumes of waste requiring disposal and the growing interest in various aspects of recycling, the volumes and composition of municipal wastes are likely to change quite significantly in the future. Composition is likely to vary since the opportunities for recycling are not uniform for all components of the solid waste stream.

Some indicative calorific values

Aggregate municipal solid waste

As an indicator of the calorific value of historical municipal solid waste streams (incorporating domestic, commercial and industrial solid wastes) in relation to other energy sources, the following data are provided:

GCV (MJ/kg)	10.8
Moisture (%)	27-30
Non-combustible (%)	14-17

There is a worldwide trend not to incinerate raw waste, but to have some preliminary sorting first (at a sorting station, or as a result of kerbside recycling, for example). When waste is sorted and the fermentable components are separated, a high quality fuel can be produced with low moisture content and relatively stable composition seasonally.

Biogas (digester gas, landfill gas)

Sources of biogas

Biogas is the name given to the gas produced by the bacterial degradation of organic matter in anaerobic (airless) conditions. In general terms, there are two categories of fermentation process – 'liquid' processes, where the solids content is very low, typically less than 10%, and 'solid' processes, where the

solids content is considerably higher, in the range 30%-35%. Most practical experience and data relate to the 'liquid' processes. The potential advantages of 'solid' fermentation processes derive from smaller digestor sizes (reduced capital costs) and a process design that recirculates the liquids, thus avoiding the need to treat and dispose of liquid effluent.

Digester gas produced at sewage works by the anaerobic digestion of sewage solids, and landfill gas (LFG) produced by the decomposition of refuse in landfills, are other forms of biogas.

Methane content and calorific value

Biogas is very similar to natural gas, of which the major fuel component is methane. It is of variable composition and can range from 40% methane and 60% carbon dioxide (with a trace of sulphide gases – usually less than 1% and often less than 0.1% by volume) to as much as 80% methane and 20% carbon dioxide. Digester gas usually contains about 65% methane and 35% carbon dioxide, but may contain 1%-5% of air or nitrogen.

A typical biogas composition from digestion of crop materials is 55% methane and 45% carbon dioxide, whilst from animal manures a typical composition would be 65% methane and 35% carbon dioxide. Sometimes the carbon dioxide content is substantially reduced by post-digestor treatment. Landfill gas usually contains 40%-55% methane and 20%-40% carbon dioxide with the balance being air or nitrogen. It may also contain a wide range of other gases in small amounts, including chlorinated hydrocarbons, depending on the refuse in the landfill.

The energy content of any biogas is calculated explicitly (on a volume % basis) from the energy content of methane (i.e. the volumetric energy content of pure methane multiplied by the volume % of methane in the particular biogas). Table 8.1 summarises typical data for biogas of various methane levels.

Methane %	Gas Density[1] kg/m^3	GCV[2] MJ/m^3	NCV[2] MJ/m^3
55	1.21	20.8	18.8
65	1.09	24.5	22.1
87	0.83	32.9	29.6
98	0.70	37.0	33.4

1 At 15ºC and 101.325 kPa (absolute) pressure
2 ±0.1 MJ/m^3

Table 8.1: Calorific values for biogas

Particular source materials

Materials with a high carbohydrate or sugar content are likely to produce biogas with close to 50% methane, whilst materials high in cellulose, oils or fats will yield higher proportions of methane.

The composition is also affected by retention time. Table 8.2 presents data on biogas production, methane content, and corresponding calorific values for a wide range of potential sources.

Rates of resource production

Indicative rates of biogas production can be estimated by linking data in Table 8.2 with that in Table 8.3, which summarises daily quantities of waste produced by various animals and birds.

Landfill Gas

There is little public domain information on the use of landfill gas in power generation in New Zealand, however there are a number of applications in

Source Material	Biogas litres/kg TS[1]	% Methane	GCV MJ/m^3
Banana (fruit & stem)	940	53	20.0
Potato (tubers)	880	54	20.4
Sugarbeet (root)	620	60	22.6
Meat waste (offal)	600	59	22.2
Lucerne	450-600	56-64	21.1-24.1
Grass	450-530	55-57	20.7-21.5
Oats (whole plant)	450-480	51-55	19.2-20.7
Kale	440-560	47-58	17.7-21.9
Sugarbeet (leaves)	380	66	24.9
MSW (organic fraction)	380	48	18.1
Lakeweed *(Lagarosiphon)*	380	56	21.1
Maize (whole plant)	350-500	50	18.9
Hay	350-460	54-65	20.4-24.5
Straw (ground)	350-450	54-58	20.4-21.9
Poultry manure (fresh)	300-450	57-70	21.5-26.4
Straw (chopped)	250-350	58	21.9
Newspaper	240	52	19.6
Cattle manure	190-220	68	25.6
Sheep manure	180-220	56	21.1
Pig manure (fresh)	170-450	55-65	20.7-24.5

1 TS = Total Solids

Table 8.2: Production of biogas from digestion of various materials at 35˚C and suitable retention times with a loading concentration of 5% total solids (Source: MAF 1985, from test data at Invermay Agricultural Centre)

Animal / Bird	Fresh manure/day kg	Total Solids[1] %	Solids/day kg
Dairy cow (500kg)	35	13	4.5
Beef steer (400kg)	25	13	3.2
Breeding sow	16	9	1.4
Sheep	3.9	25	1.25
Fattening pig (50kg)	3.3	9	0.3
Turkey (5.5kg)	0.4	25	0.09
Layer hen (2kg)	0.12	25	0.03
Meat chicken (1kg)	0.10	21	0.02

1 Varies with diet, etc.

Table 8.3: Daily quantities of waste produced by various animals and birds (Source: MAF 1985, from test data at Invermay Agricultural Centre)

service in the Hutt Valley and Auckland. Typically these facilities are connected to the local distribution network.

Table 8.4 shows the main constituents of landfill gas and their proportions. Methane is a greenhouse gas and also poses explosion hazards if uncontrolled. Other landfill gas constituents, such as non-methane organic compounds, are pollutants and others pose health hazards due to their toxicity.

Other solid wastes

Typical energy content and resource characteristics for a variety of solid waste materials are shown in Table 8.5.

Constituent Gas	Concentration in Landfill Gas	
	Range	Average
Methane (CH_4)	35% - 60%	50%
Carbon Dioxide (CO_2)	35% - 55%	45%
Nitrogen (N_2)	0% - 20%	5%
Oxygen (O_2)	0% - 2.5%	<1%
Hydrogen Sulfide (H_2S)	1 - 1,700 ppmv	21 ppmv
Halides	NA	132 ppmv
Water Vapor (H_2O)	1% - 10%	NA
Nonmethane Organic Compounds	237 - 14,294 ppmv	2,700 ppmv

NA = not available. ppmv = parts per million by volume. Note: Highest values occur in perimeter wells.

Sources: G.J. Sandelli, Demonstration of Fuel Cells To Recover Energy from Landfill Gas. Phase I Final Report: Conceptual Study, EPA-600-R-92-007, prepared for the U.S. Environmental Protection Agency by International Fuel Cells Corporation (Washington, DC, January 1992); M. Doorn, J. Pacey, and D. Augenstein, Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends, EPA-600/R-95-035, prepared for the Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency by E.H. Pechan and Associates, Inc. (Washington, DC, March 1995).

Table 8.4: Main constituents of landfill gas

Waste	Ash %	Moisture %	Gross heat value kcal/kg
Animal fats	-	-	9,500
Corn cobs	3	5	4,500
Paint	-	-	4,500
Paper	1	5	4,000
Rubber	20	30	5,500
Pathological waste	3	85	550
Wood	3	10	5,000

Source: International solid Waste Association, 1997

Table 8.5: Some typical waste fuels and their approximate characteristics

9 Solar

Character of the resource

Solar energy is the largest energy flux supporting human and natural systems. A source temperature of 6000 K means solar radiation is of potentially high thermodynamic quality. It is, however, at relatively low concentration by the time it reaches the earth. Nevertheless, solar energy leads to more concentrated forms of energy via photo-chemical or direct heating processes. Harnessing it directly is most often associated with building design for space heating and solar water heating, or with biomass capture in the form of trees or other specialist crops.

Global solar fluxes

Over one third of the incoming radiation is reflected by atmospheric constituents or at the surface of the land and oceans, as indicated in Table 9.1. Most of the absorbed solar energy goes directly into heating processes, giving rise to thermal currents in the form of winds and ocean currents, as well as evaporating water as part of the hydrological cycle. As a global average, only 0.1% of incoming radiation is involved in biological photosynthesis.

Direct solar input to New Zealand

In New Zealand, mean daily insolation is 14.1 MJ/m^2/day or 163 W/m^2. With a total land area of 2.69 x 10^{11} m^2, the solar energy flux at the land surface is 44TW or 1.39 x 10^{21} J/year. A certain proportion of the incoming radiation, referred to as the albedo (see Table 9.2), is reflected immediately.

By way of illustration, the intensity of the sun on a bright day in New Zealand can often reach 1 kW/m^2. In such cases, a solar collector of just a few square metres, such as that seen on the roofs of some New Zealand homes, is sufficient to provide useful input for water-heating purposes. However, solar energy is intermittent, varying during the day and is also highly variable seasonally. Thus, even though heated water may be stored, a backup source of energy, such as a solar/electric system, is required to deliver reliable hot water.

Description of flux	Mean annual energy input ZJ/yr (horizontal surface)	Percentage incident flux
Incident solar energy to Earth	5688	100
Reflected by clouds	1363	24
Reflected by atmosphere	324	6
Reflected by Earth's surface	346	6
Absorbed by clouds	151	3
Absorbed by atmosphere	822	14
Absorbed by Earth's surface	2682	47

Note: 1 zettajoule = 10^{21} J

Table 9.1: Disposition of the mean annual solar radiation incident on the earth-atmosphere system (Source: Baines and Smith, 1982)

Type of land surface	Land area (million ha)	Albedo
Pasture / arable lands	14.4	0.25
Forest lands	7.2	0.10
Remaining lands	5.3	0.28
All New Zealand	26.9	0.22

Table 9.2: Typical values for albedo for various land surfaces

In general, while the figures presented here indicate that solar energy is plentiful (in comparison to world energy usage, which was approximately 0.5ZJ in 2004), harnessing it for uses beyond the standard ones such as photosynthesis and ambient heating is a problem, especially in an economic manner.

Seasonal and geographical variation in solar input

For any calculation purposes, or to get an indication of the amount of solar energy available in different parts of the country, the solar radiation (MJ/m^2) must be used. (In the past the duration of sunshine has been considered, but correlation between sunshine hours and solar radiation can be poor and is no basis for reliable calculations.) The solar radiation varies with season and geographic location throughout the country. Typically three components of radiation will be considered and a combination used depending on the application. These are:

- Global: Total amount of solar radiation incident on the surface of the earth (on a horizontal surface).
- Direct: Amount of solar radiation at the Earth's surface on a flat surface perpendicular to the sun's beam with surrounding sky radiation blocked.
- Diffuse: Amount of solar radiation incident on the surface of the earth under all-sky conditions with direct radiation from the sun's beam blocked by a shadow band or tracking disk at the Earth's surface.

Data for solar radiation intensity are typically presented in units of MJ/m^2/day. The historical unit was langleys/day, measured on the international pyrheliometric scale (IPS). For conversion use 1 Langley = 0.04278 MJ/m^2.

For modern calculation purposes, hourly data should be considered. These are now available from a variety of sources:

- **Sustainable Electricity Association of New Zealand** www.seanz.org.nz
- **NIWA** www.niwa.cri.nz
- **NASA** http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?rets@nrcan.gc.ca (Data generated from satellite measurements. This will be less accurate than actual ground based measurement.)

(As with all web links, the above may change over time, but a web search using some of the text above should find the data.)

Location[2]	Solar Radiation (or global irradiance, MJ/m^2/day)[1]												
	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kaitaia Aero	14.7	22.4	18.6	15.1	11.9	8.8	7.1	8.0	10.4	14.6	17.6	20.1	22.7
Whangarei Aero AWS	13.8	20.4	18.0	14.8	11.1	7.8	6.7	7.4	10.1	13.2	17.1	19.0	21.1
Rotorua Aero	14.9	22.6	20.1	15.7	11.8	8.8	7.0	7.9	9.9	13.9	17.8	21.0	22.4
Auckland Aero	14.7	22.8	19.5	15.8	11.8	8.3	6.3	7.5	10.1	14.0	17.7	21.0	22.5
New Plymouth AWS	14.7	22.6	21.1	16.1	11.3	7.6	6.2	7.0	9.5	12.9	17.3	20.6	23.8
Masterton/East Taratahi AWS	13.7	23.2	19.0	15.3	9.9	7.1	5.5	5.9	8.6	12.9	17.4	19.8	22.1
Gisborne Aero	14.4	23.3	19.4	14.9	10.6	7.6	5.8	6.7	9.2	13.6	18.1	22.2	23.6
Napier Aero AWS	14.7	22.5	19.0	15.5	10.8	8.0	6.5	6.7	9.7	13.9	18.8	20.8	22.7
Paraparaumu Aero	13.7	21.4	19.7	15.2	10.1	6.9	5.0	5.8	8.7	12.0	16.3	20.4	23.0
Palmerston North AWS	13.5	21.2	19.4	15.3	10.1	6.9	5.2	6.0	8.5	11.6	16.0	18.7	22.2
Wellington, Kelburn	14.1	23.1	19.5	15.1	10.4	6.7	4.9	5.7	8.1	12.1	17.2	20.8	24.2
Hokitika Aero	12.6	20.3	17.9	14.0	9.2	5.7	4.5	5.4	7.8	11.7	15.2	19.1	21.1
Nelson Aero	14.7	23.4	21.0	15.7	11.5	7.5	5.6	6.4	8.9	13.4	18.1	21.6	23.5
Kaikoura AWS	13.7	22.9	19.2	15.2	10.1	6.9	5.4	5.9	8.8	12.5	17.5	21.4	21.7
Winchmore EWS	13.6	22.3	18.3	14.5	9.8	6.3	4.9	5.5	8.1	12.6	17.4	20.1	22.0
Christchurch Aero	13.2	22.3	18.8	14.4	9.2	6.1	4.6	5.3	7.8	12.0	16.6	20.6	21.7
Dunedin Aero	12.1	20.1	17.0	13.0	8.6	5.1	4.0	4.6	7.1	11.4	14.7	18.8	20.1
Queenstown Aero AWS	14.2	24.4	20.8	15.7	10.5	6.1	4.6	5.8	8.4	13.3	18.3	21.7	23.4
Lauder EWS	14.2	23.6	19.3	15.9	10.5	6.1	4.5	5.4	8.2	12.7	17.0	21.4	22.2
Invercargill Aero	12.1	21.6	17.6	12.7	7.8	4.5	3.6	4.3	7.1	11.2	15.5	20.0	20.2

1 Based on data from the period 1971-2000 for horizontal surfaces

Table 9.3: New Zealand solar radiation intensity (MJ/m^2/day)

10 Wind

Character of the resource

Winds arise principally from temperature differences at the Earth's surface caused by uneven absorption of sunlight. Air heated by contact with a warmer surface will rise causing cooler air to flow in and take its place.

The resulting airflow we call wind. The energy of motion (kinetic energy) in wind has provided a source of mechanical energy for centuries. Early use centred on direct mechanical pumping while latterly technology has evolved to link wind turbines to electric generators.

New Zealand has an excellent wind resource because of its oceanic location and a fairly steady succession of troughs and depressions passing west to east. Each weather system induces a pressure pattern over the mountains and this can lead to almost continuous winds in some parts of the country.

Mean wind energy fluxes in New Zealand are more concentrated than the mean solar flux. Certain regions have mean wind energy fluxes greater that 400 W/m^2, with some locations as high as 2000-2500 W/m^2. (Note that the solar flux is measured over a horizontal area, while wind flux is measured over a vertical area.)

Quantifying the wind resource

The usefulness of wind for energy is assessed in terms of annual mean wind speed (AMWS) rather than instantaneous wind speed. A speed of 3-4 metres per second is a typical 'cut in' wind speed for electricity generation. Wind turbines typically achieve maximum electricity output at around 12-15 metres per second and shutdown at wind speeds greater than 25 metres per second to avoid damage.

Measuring this wind speed is vital for wind farm developers so that they have a good understanding about the best locations for wind farms. It is, broadly speaking, possible to measure the wind speed in two ways.

One can either take physical measurements using an anemometer or 'met mast' as it tends to be known in the industry. More recently, developers have turned to SODAR (sonic detection and ranging) or LIDAR (Light Detection and Ranging) measurement that can be installed at ground level to support the met mast measurements. While this method is very accurate it is expensive if one is seeking to acquire information about average wind speeds, over long periods of time, across the entire country.

Alternatively, with the assistance of today's powerful computers, it is possible to carry out sophisticated modelling of wind speeds. This modelling can be done at four levels of accuracy:

- **Synoptic scale** modelling looks at weather systems with dimensions of several hundred kilometres or more.
- **Meso-scale** modelling typically ranges from 80 km through to several hundred kilometres.
- **Storm scale** modelling refers to the analysis of individual weather events (e.g. thunderstorms) and consequently is concerned with features ranging in size from a kilometre up to

50 kilometres.

- **Micro-scale** modelling is concerned with modelling wind speeds at a resolution down to as low as 200 metres.

While modelled predictions of wind speed patterns are useful indicators of relative wind resource across the country and the potential of a particular site, wind farm developers do not rely on such modelled predictions.

Actual, continuous measurements of wind speeds on prospective sites are generally undertaken to confirm commercial viability. The met masts used will have provision for measuring wind speeds at various heights above the ground, up to the intended hub height. With the latest technology, the hub height can be as high as 100 m above the ground, though 80 m is most typical.

Table 10.1 shows wind speeds on a monthly basis at various North Island and South Island locations. Mean annual wind speeds for the North and South Islands are shown in Figures 10.1 and 10.2, respectively.

The nature of wind variability

Instantaneous wind speed is inherently very variable. However, when summed over climatic seasons or calendar years, records indicate average wind speeds are relatively constant. For example, analyses by Smyth (1987) suggest a 1-in-20 year low for wind energy that is 10% below the long-run mean. The corresponding deviation for hydro lake storage levels is 15%.

Data from the first 10 years of operation of the Brooklyn wind turbine and the first 4 years of the Tararua Stage 1 wind farm, supports this 10% range in variability of the wind resource over time.

The Electricity Commission has now commissioned two reports from Transpower[1] which have looked at the nature of wind variability, in the short term (minutes and hours), and the potential affects of that variability on the stability of the grid. The reports identify a number of operational issues associated with the rapid uptake of wind energy and notes that these issues are manageable.

Potential wind farms

Operational

Table 10.2 shows currently operational wind farms around the country.

Planned and potential projects

There are a number of developments currently being considered around New Zealand. The nature of the development of wind farm sites is such that many projects do not get beyond the initial assessment phase and, as a result of that initial assessment are not subsequently submitted to the planning process.

Figure 10.3 depicts existing, consented and potential windfarms which have been or are being investigated in New Zealand.

[1] 'Manawatu wind generation: Observed impacts on the scheduling and dispatch process' Part 1 – February 2005; Part 2 – September 2005.

Location[2]	Median Wind Speed[1]												
	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kaitaia Aero	4.5	4.0	4.2	4.3	4.2	4.2	4.4	4.8	4.6	4.9	5.0	4.5	4.6
Whangarei Aero AWS	3.3	3.3	3.2	3.1	2.7	2.9	2.7	3.2	3.3	3.2	3.6	3.9	3.5
Rotorua Aero	3.4	3.7	3.3	3.1	2.9	2.9	3.0	3.0	3.0	3.7	4.1	3.7	3.9
Auckland Aero	4.9	5.1	4.8	4.5	4.3	4.7	4.3	4.6	4.8	5.4	5.7	5.8	5.3
New Plymouth AWS	5.1	4.8	4.7	5.0	4.3	4.9	5.1	4.9	5.0	5.1	5.6	5.6	5.2
Masterton/East Taratahi AWS	3.4	3.1	3.1	2.9	2.7	2.8	3.1	2.7	3.3	3.5	3.6	3.7	3.7
Gisborne Aero	4.1	4.2	4.0	4.1	3.9	4.0	3.9	3.9	4.1	4.3	4.6	4.6	4.6
Napier Aero AWS	3.8	3.9	3.6	3.6	3.2	3.5	3.4	3.6	3.8	3.8	4.2	4.5	4.3
Paraparaumu Aero	4.8	5.0	4.3	4.1	4.3	4.5	4.5	4.5	4.4	4.9	5.2	5.1	5.0
Palmerston North AWS	4.3	4.5	4.3	4.2	3.6	3.7	3.8	3.7	4.1	4.4	4.8	5.1	4.5
Wellington, Kelburn	6.0	6.4	5.8	5.7	5.5	5.8	5.4	5.5	5.6	6.3	6.7	6.5	6.7
Hokitika Aero	3.1	3.2	3.0	2.9	2.8	2.8	2.6	2.6	3.0	3.3	3.5	3.5	3.5
Nelson Aero	3.2	4.2	3.5	3.2	2.9	2.5	2.1	1.8	2.2	3.4	4.0	4.3	4.3
Kaikoura AWS	4.5	4.8	4.3	4.3	4.4	4.4	4.2	4.1	4.6	4.5	4.5	4.9	4.8
Winchmore EWS	3.0	3.2	3.1	2.9	2.7	2.6	2.3	2.3	2.4	3.2	3.3	3.3	3.4
Christchurch Aero	4.1	4.9	4.8	4.2	3.7	3.4	3.2	3.3	3.8	4.1	4.5	4.8	5.0
Dunedin Aero	3.9	4.4	3.9	3.6	3.5	3.9	3.4	3.2	3.5	4.2	4.3	4.3	4.2
Queenstown Aero AWS	3.2	3.7	3.5	3.2	3.0	2.8	2.7	2.6	2.8	3.2	3.4	3.7	3.6
Lauder EWS	3.1	3.6	3.3	2.9	2.4	2.5	2.2	1.9	2.5	3.4	3.9	3.6	3.8
Invercargill Aero	4.9	5.4	5.0	4.8	4.4	4.7	3.9	3.6	4.0	5.3	5.8	6.0	5.4

1 Measurements typically at 10m above ground. Wind speed at hub height is generally higher. Terrain effects can also cause localized wind speed increases (i.e. top of ridges)

Table 10.1: New Zealand median wind speeds, 1971 - 2000 (Source: NIWA)

Site	Operator	When commissioned	Region	No. of Turbines	Turbine capacity MW	Project capacity MW
White Hill	Meridian	2007	Southland	29	2.0	58.0
Tararua 3	TrustPower	2007	Manawatu	31	3.0	93.0
Te Rere Hau	NZ Windfarms	2006	Manawatu	5 (of 97)	0.5	2.5 [1]
Southbridge	Energy3	2005	Canterbury	1	0.1	0.1
Te Apiti	Meridian	2004	Manawatu	55	1.65	90.8
Tararua 2	TrustPower	2004	Manawatu	55	0.66	36.3
Hau Nui 2	Genesis	2004	Wairarapa	8	0.6	4.8
Gebbies Pass	Windflow	2003	Canterbury	1	0.5	0.5
Tararua 1	TrustPower	1999	Manawatu	48	0.66	31.7
Hau Nui 1	Genesis	1996	Wairarapa	7	0.55	3.9
Brooklyn	Meridian	1993	Wellington	1	0.225	0.225
TOTAL	-	-	-	241	-	321.8

1 Increases to 48.5 MW when all turbines installed in this stage. Forty-four further turbines are scheduled to be installed 2008-2009.

Table 10.2: Current Operational Windfarms in New Zealand (July 2007) (Source: New Zealand Wind Energy Association)

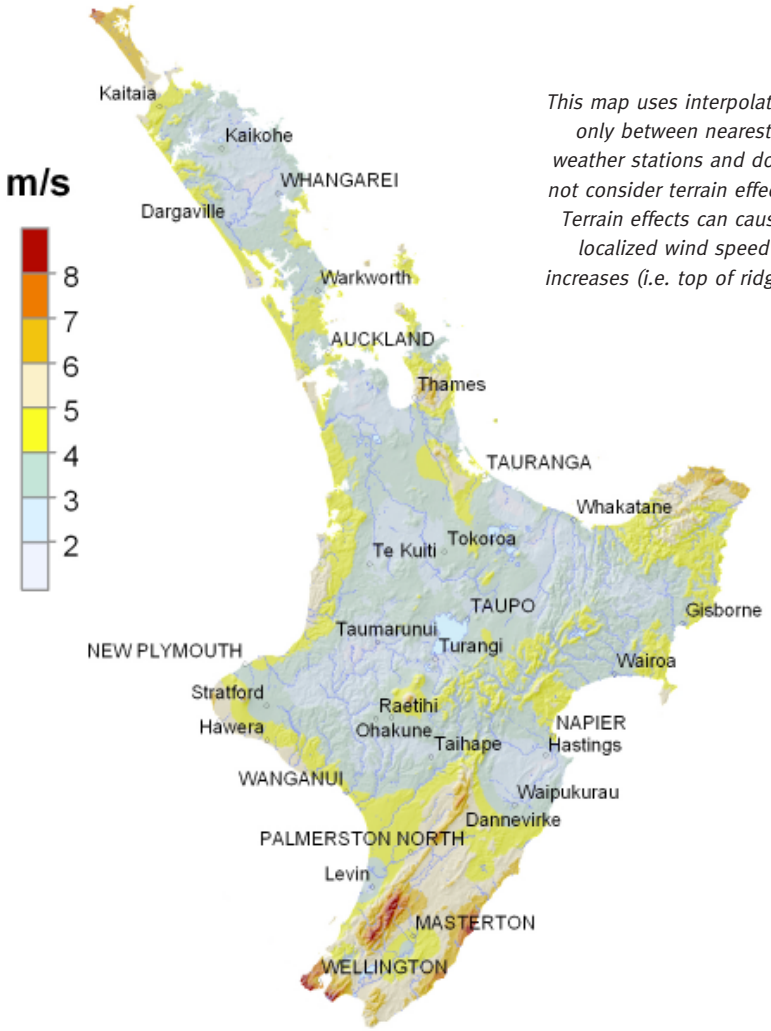

Figure 10.1: North Island mean annual wind speeds at 10m above ground, 1971-2000 (Source: NIWA)

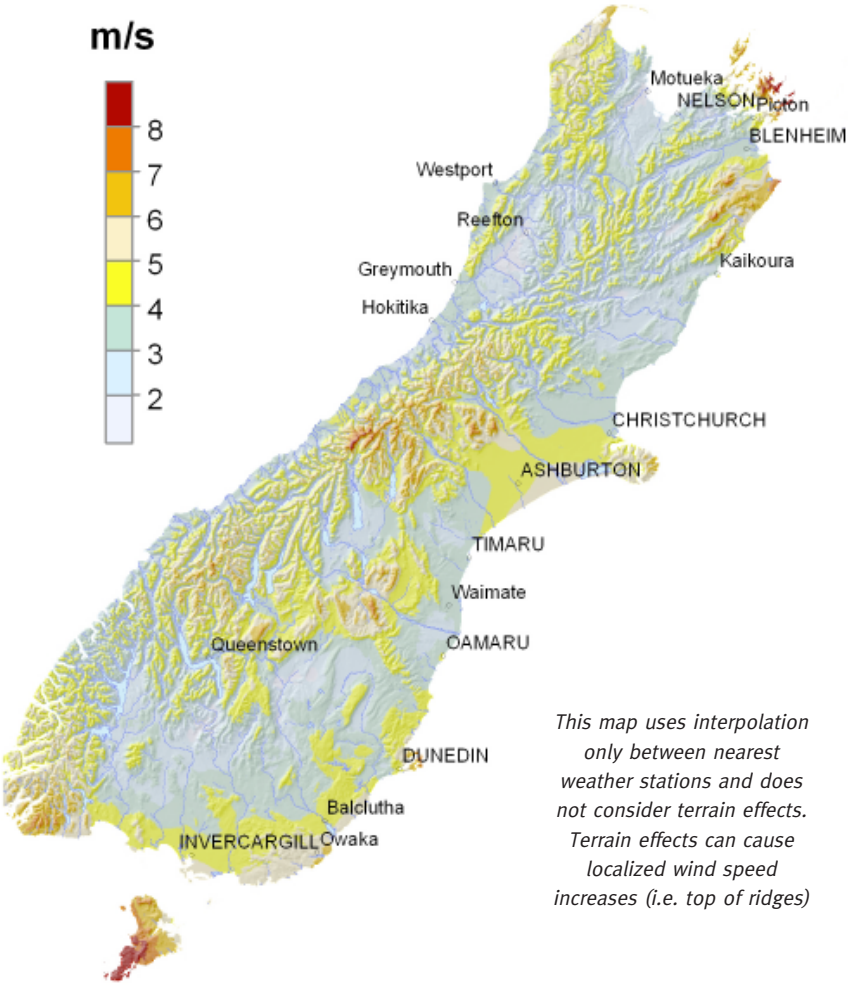

Figure 10.2: South Island mean annual wind speeds at 10m above ground, 1971-2000 (Source: NIWA)

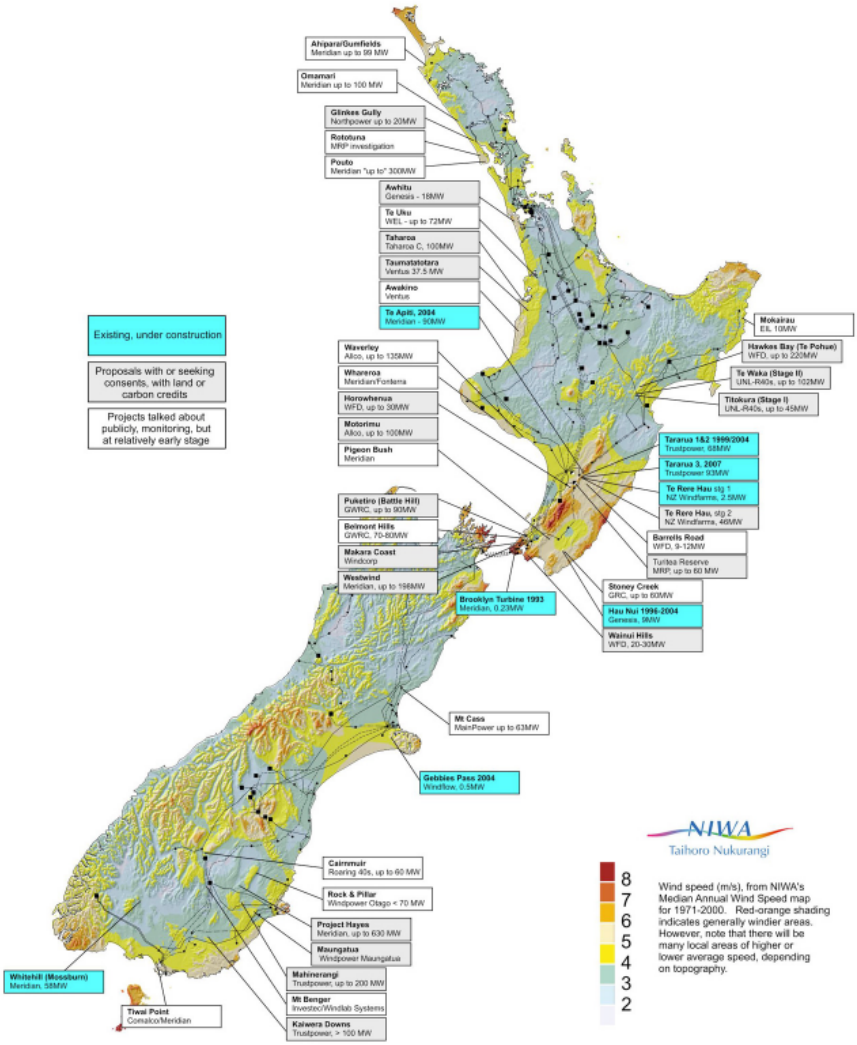

Figure 10.3: Current and Proposed Windfarms in New Zealand. Sizes and locations are indicative only, based on media reports and other public sources (Source: NIWA (base map) and Transpower (generation), August 2007)

11 Oceans

Character of the Resource

The ocean is a large untapped potential energy resource, but the technical capacity to harness this resource remains uncertain. Potentially useable energy is contained in salinity gradients, temperature gradients, ocean currents, tidal streams, waves, and tidal rises and falls. At present, no commercial technology exists to harness any of these, although advances in wave and tidal energy systems offer commercial potential.

The use of salinity gradients for power generation has been proposed in theory, but to date never trialed beyond small-scale demonstration plants[1].

Ocean temperature gradients can be exploited by means of heat engines. The technology is referred to as Ocean Thermal Energy Conversion (OTEC). Cold water from deep beneath the surface is pumped up and the temperature difference to warm surface water used to drive a heat engine. Technically achievable efficiencies are around 3%[2]. The technology is only viable if temperature differences are 20˚C or more, limiting its scope to the tropical climate zones, approximately +/- 20˚ of the equator. OTEC is therefore not an option for New Zealand.

Tidal ranges maybe harnessed by barraged tidal power plants. This, however, is applicable only in places with large tidal variations. The oldest tidal plant was installed near Saint-Malo, France, with a tidal range of 12 to 16 meters. This compares to a tidal range of generally less than 2 meters in New Zealand[3]. A major drawback of this technology is the fact that electricity can only be generated for short periods of time per day.

At this stage, the only types of marine energy with potential for New Zealand are wave energy and ocean currents, including tidal streams.

Wave Power

The wave power potential around New Zealand is considered relatively attractive[4]. The energy potential depends on average wave heights, and is expressed in available energy per meter of wave front (kW/m). Energy densities are in excess of 100 kW/m for the southern coast of the South Island and around 25 kW/m on the more sheltered Eastern and Northern coasts[5]. Proposed technologies for harnessing wave power are either coast-attached breaking devices or off-shore swell devices.

Wave heights and period for New Zealand are given in Table 11.1 and shown diagrammatically in Figure 11.1.

Ocean and tidal currents

Ocean currents or tidal streams may be

1 Jones, A T and Finley, W, 2003. *Recent Developments in Salinity Gradient Power*, available at ieeexplore.ieee.org/iel5/9015/28617/01282847.pdf.

2 Vega, L A, 1999. *Ocean Thermal Energy Conversion (OTEC)*, available at www.otecnews.org.

3 EECA, 2005. *Marine Energy Fact Sheet*, available at www.eeca.govt.nz.

4 Cavanagh, J E, Clarke, J H and Price, R, 1993. Chapter 12, *Ocean Energy Systems*, p513-547 of *Renewable Energy: Sources for Fuels and Electricity*, Island Press, Washington DC, 1993.

5 Power Projects Ltd., 2005. Marine Energy, 2005: Summary of Current Developments and Outlook for New Zealand, available at www.eeca.govt.nz.

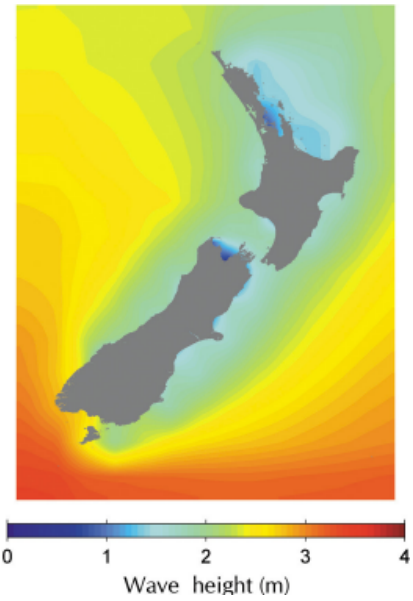

Figure 11.1: Mean significant wave heights (1979-1998) (Source, NIWA)

the most promising and most widely applicable form of ocean energy. Tidal streams are exploited with tidal stream generators. Due to the similar mode of operation, these are sometimes compared to wind turbines. The main advantages of tidal generators over wind turbines are the much higher energy density of water versus wind, and the higher predictability of tidal streams. The tidal stream energy potential is a function of the stream velocity, where the power increases with the cube of stream velocity. Water current velocities for selected locations in New Zealand are listed in Table 11.2.

Potential Issues

At this early stage of development marine energy technologies are generally expensive to build and maintain because of the highly corrosive environment and engineering complexity. Depending on plant location, long cables may need to be installed for grid connection. Submarine cables are key costs for marine energy schemes.

Marine energy technologies may also have significant environmental impacts, such as the destruction of shore lines and of whole marine ecosystems. Existing wave power pilot projects performed poorly and achieved very small fractions of design power outputs. Tidal stream plants are likely to be less site-flexible than wave power plants.

Node	Lon	Lat	Mean		Hs		
			Hs	Tp	5%	50%	95%
	° E	° N	m	s	m	m	M
W Stewart	167.50	-47.00	3.18	11.3	1.59	2.97	5.57
E Foveaux	168.75	-47.00	2.53	10.9	1.29	2.31	4.52
Otago	171.25	-46.00	1.84	9.5	0.93	1.68	3.33
Waitaki	171.25	-45.00	1.22	8.0	0.54	1.11	2.28
Ellesmere	172.50	-44.00	1.21	7.5	0.56	1.11	2.25
N Canterbury	173.75	-43.00	1.54	8.5	0.73	1.40	2.92
Palliser	175.00	-42.00	1.77	8.1	0.85	1.63	3.29
Wairarapa	176.25	-41.00	1.63	8.9	0.71	1.45	3.21
Kidnappers	177.50	-40.00	1.71	9.0	0.75	1.51	3.37
Poverty	178.75	-39.00	2.07	9.0	1.03	1.86	3.85
E Cape	178.75	-38.00	1.93	8.7	1.00	1.77	3.42
Bay of Plenty	177.50	-37.00	1.69	7.2	0.71	1.53	3.20
E Coromandel	176.25	-37.00	1.38	7.2	0.51	1.23	2.82
Hauraki	175.00	-36.00	1.34	7.4	0.49	1.17	2.79
Bay of Islands	175.00	-35.00	1.58	7.4	0.65	1.41	3.16
N Cape	173.75	-34.00	2.09	9.7	1.13	1.93	3.59
3 Kings	172.50	-34.00	2.65	10.8	1.50	2.50	4.35
90 Mile Beach	172.50	-35.00	2.46	11.2	1.26	2.28	4.25
Hokianga	172.50	-36.00	2.64	11.2	1.28	2.46	4.63
Kaipara	173.75	-37.00	2.16	11.1	1.00	1.98	3.92
Raglan	173.75	-38.00	2.13	10.4	0.95	1.96	3.90
New Plymouth	173.75	-39.00	1.92	9.5	0.81	1.78	3.56
S Taranaki	173.75	-40.00	1.58	7.9	0.59	1.47	2.94
Farewell	172.50	-40.00	2.34	10.1	1.09	2.18	4.14
Heaphy	171.25	-41.00	2.49	10.8	1.16	2.30	4.45
Foulwind	171.25	-42.00	2.03	10.5	0.86	1.84	3.84
Harihari	170.00	-43.00	1.97	10.2	0.82	1.77	3.80
Jackson Bay	167.50	-44.00	2.56	11.0	1.26	2.38	4.45
Fiordland	166.25	-45.00	3.25	11.2	1.68	3.06	5.47
Puysegur	166.25	-46.00	3.44	11.3	1.74	3.24	5.85
Chathams	183.75	-44.00	3.18	10.4	1.74	2.97	5.35

Notes

1. Wave heights are significant wave heights in deep water, given by $4\sqrt{M_o}$, where M_0 is the area under the Fourier spectrum.
2. Periods are peak periods (i.e., the period of the peak in the Fourier spectrum).
3. Data come from the NOAA Wave Watch 3 (NWW3) model http://polar.ncep.noaa.gov/waves/Welcome.html
4. Locations are at nodes of the model grid which has intervals of 1.25° in longitude and 1° in latitude.

Table 11.1: New Zealand wave heights and periods

Node	Longitude	Latitude	Mean Speed	5% Speed	50% Speed	95% Speed	Max Speed
W Stewart	167.75	-46.75	0.38	0.19	0.38	0.55	0.61
E Stewart	168.75	-47.00	0.29	0.13	0.30	0.46	0.53
Catlins	169.75	-46.75	0.08	0.03	0.08	0.13	0.15
Waitaki	171.75	-45.00	0.02	0.01	0.02	0.04	0.05
Mernoo	173.75	-43.50	0.07	0.03	0.08	0.12	0.14
Cook	174.75	-41.50	0.17	0.09	0.16	0.25	0.28
Wairarapa	176.00	-41.25	0.03	0.01	0.03	0.04	0.05
Colville	175.50	-36.50	0.18	0.05	0.19	0.30	0.32
Reinga	172.75	-34.25	0.10	0.03	0.11	0.16	0.19
3 Kings	171.75	-34.00	0.08	0.02	0.08	0.16	0.20
Kaipara	174.00	-36.25	0.26	0.08	0.26	0.45	0.51
Waikato	174.75	-37.50	0.14	0.03	0.14	0.25	0.28
N Plymouth	173.00	-38.75	0.08	0.04	0.08	0.13	0.15
S Taranaki	174.25	-39.75	0.22	0.06	0.22	0.38	0.45
Wanganui	175.25	-40.50	0.28	0.09	0.27	0.47	0.54
D'Urville	174.00	-40.75	0.24	0.06	0.26	0.39	0.43
Farewell	172.75	-40.50	0.09	0.04	0.09	0.15	0.17
Foulwind	171.50	-41.75	0.47	0.11	0.48	0.82	0.99
Fiordland	166.00	-46.50	0.09	0.04	0.09	0.14	0.17
Chatham	183.25	-43.75	0.76	0.15	0.77	1.36	1.73

Notes

1. Tidal constituents were obtained from the Oregon State University global tide model TPXO Version 7 available from: http://www.coas.oregonstate.edu/research/po/research/tide/global.html.
2. Constituents are available at 0.25° intervals in latitude and longitude for 10 tides (M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1, M_f, and M_m), of which the first 8 were used, being the primary tides for New Zealand.
3. Tidal current statistics were calculated by synthesizing the constituents at 15 minute intervals for 1 year.
4. The sites were chosen as the 20 nodes with the largest maximum M_2 current speed around the NZ coast. Other nodes with large currents may occur within 1° of latitude and longitude of the sites listed.
5. For areas with complex bathymetry and shorelines, and where the currents are spatially highly variable (such as Cook Strait), the model resolution is much too coarse to adequately define the current speeds, and a local-area model should be used to refine the statistics.

Table 11.2: New Zealand water current speeds (current speeds are in m/s)

12 Emerging Forms of Energy

Biofuels

In an age of growing environmental concern and of constrained supplies of liquid fuels from crude oil, notably transport fuels, biofuels hold the promise of extending and replacing traditional sources of oil-based energy.

In general, biofuels can be manufactured from a large range of biomass sources/ feedstocks. Additionally, different types of biofuel crops can be grown in numerous locations. Sourcing fuels/energy from biomass creates a considerable range of diversity from both the biomass source and geography points of view.

Given constrained and increasingly expensive oil supplies, much of it from volatile parts of the world, these aspects have the potential to contribute greatly to energy security.

Unsurprisingly, the economics of manufacturing biofuels from different sources varies considerably, depending on parameters such as competition for the feedstock (food), competition for arable land, land costs, growing costs, the costs of the fuel manufacturing processes, the environmental effects of growing biofuels crops and the environmental effects of converting the crop into useful fuel.

The greenhouse gas content embodied in biofuels, emitted upon combustion, is considered neutral as it is then absorbed during the growth cycle of the biofuel crop. However, the growing, harvesting, extraction, refining and processing required to arrive at useable biofuels is not carbon neutral as, more often than not, fossil fuels are used to enable these steps. Thus, to a greater or lesser extent, carbon is emitted during the conversion process from crop to useful energy. In this sense, some biofuels are more 'CO_2 efficient' than others.

Tables 12.1 – 12.4 give some indicative estimates of effective energy and carbon intensity for a limited range of biofuel sources.

Petrol: Ethanol	100:67
Diesel: Biodiesel	100:86

Table 12.1: Relative energy content of biofuels (volumetric)

Corn ethanol (petrol)	1.3
Sugarcane ethanol (petrol)	8.0
Cellulosic ethanol (petrol) (eg. From wood or agricultural wastes, switchgrass, salix)	2 - 36
Canola (diesel)	2.5

Table 12.2: Energy balance from some feedstocks (per unit of fossil fuel input)

Corn ethanol (petrol)	77% (1)
Sugarcane ethanol (petrol)	10% - 45% (2)
Cellulosic ethanol (petrol)	10%
Canola (diesel)	32%

Crutzen & Smith in *Atmospheric Chemistry and Physics Discussions*, Sept. 2007 estimate a range of 90-150% for (1) and 50-90% for (2)

Table 12.3: Relative GHG emissions (from production and use – Petrol/Diesel = 100%)

Fuel	Productivity L/ha/yr
Corn ethanol (petrol)	2800
Sugarcane ethanol (petrol)	5600 - 7500
Canola (diesel)	500 - 800
Soybeans	550
Peanuts	1000
Palm Oil	6000
Jatropha	12000
Algae (theoretical)	47000 - 65000

Table 12.4: Productivity – indicative for some feedstocks (litres/hectare/year)

(Sources for Tables 12.1 – 12.4: US Dept of Energy, US Environmental Protection Agency, various.)

Figure 12.1 gives some indication of the different pathways that are currently employed to transform biomass into liquid fuels.

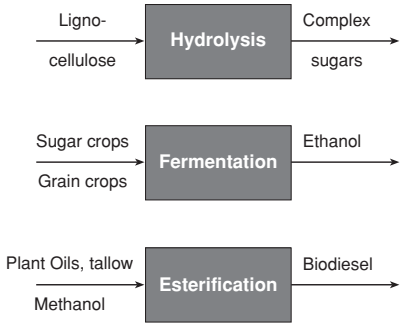

Figure 12.1: Current biofuels transformation Processes

From the yield and carbon emissions points of view, biodiesel from algae holds considerable conceptual promise. Algae thrive and depend on the capture of CO_2 in order to grow and produce energy. The same algae may also be able to absorb other impurities such as nitrates.

Unlike many other biofuel feedstocks, algae have not only huge productivity per unit area, but will often thrive in areas that are not arable and which do not compete for other uses such as ponds or bogs.

However, due in part to its high water content, the path to useful fuel is not well developed with most processes being largely experimental and costly.

In contrast, most of the other feedstock options described in Tables 12.1-12.4 and summarised in Figure 12.1 are established processes, even if some of them are not as high yield, have competing uses, and may not be very carbon-beneficial.

Potential petrol substitutes (alcohols, MTBE)

Liquid fuels are currently the principal source of energy in the Western world. A great many fuels fall into this category, most of which are oil-based products. There are, however, a number of alternatives to oil-based fuels, and in the field of transport the more important currently appear to be the alcohols and various vegetable and animal oils and fats. These fuels are designed to blend with or substitute for petrol in spark ignition engines and diesel fuel in compression ignition engines.

The alcohols

The alcohols, methanol and ethanol, are suitable for use in spark ignition engines. They may be used alone or blended with petrol. Low percentage blends of alcohol with petrol may not require any engine or vehicle modifications and as such may be

used as a petrol extender. High alcohol blends require a number of engine modifications if their full potential is to be realised. One reason for engine modifications is the incompatibility of alcohols with conventional engine and vehicle materials, leading to problems of corrosion.

Sources

Methanol can be obtained from a variety of sources – gasification of coal or wood, or reforming of natural gas, currently the cheapest source for large-scale production.

Ethanol can be produced from ethylene (derived from oil) or by the fermentation and distillation of sugars from various agricultural crops (eg. sugar cane, beet and corn) or whey, a by-product of milk processing.

Since the alcohols are oxygenated fuels they require less air for combustion of a unit mass of fuel. However their calorific value is approximately half that of petrol, hence nearly twice as much fuel must be burnt within an engine cylinder in order to obtain an equivalent power output.

Alcohol-petrol blended fuels

Low alcohol blends consist of up to 10% alcohol in petrol. Only minor engine changes may be necessary with such blends.

High alcohol blends consist of up to 85% alcohol in petrol. The small percentage of petrol is present to ensure adequate cold starting.

In addition to the material compatibility problems mentioned above, blended fuels can have phase separation problems. As ethanol and methanol are totally miscible with water, the miscibility of both alcohols in petrol is reduced by the presence of water, and is further reduced at cooler temperatures.

The current trend is to operate vehicles with a flexible fuelling system. A flexible fuelled vehicle is designed to run on any percentage blend of ethanol and petrol up to a maximum of 85% alcohol. One hundred percent ethanol is available as a vehicle fuel in Brazil.

However, relatively little data has been published on fuel economy and emissions for engines operating with fuel blends ranging between 10% and 85% ethanol. Thus there has been little effort made to optimise engine efficiency over this range to the point that would offset the additional fuel cost.

MTBE

The alcohols may themselves be used as a feedstock, with iso-butane, for the production of methyl tertiary butyl ether, MTBE, or ethyl tertiary butyl ether, ETBE. These blends have higher specific energies when compared to the base alcohols.

Furthermore, the anti-knock qualities of MTBE and ETBE are superior to the alcohols and therefore may be used as non lead-based octane boosters in petrol. They also have the advantage of lower enthalpies of vaporisation and do not suffer water separation problems when blended with petrol due to a high miscibility with all hydrocarbon fuels and a low solubility with water.

The use of MTBE gained some popularity in the 1990s. However, suspected carcinogenic issues have resulted in its use falling from favour. Ethanol, which is more expensive, is generally regarded as a suitable substitute. It has an octane

Fuel	Specific Gravity[1]	GCV		NCV	
		MJ/kg[2]	MJ/l[3]	MJ/kg[2]	MJ/l[3]
Petrol	0.73	47.2	34.5	44.4	32.4
Methanol	0.80	22.3	17.8	19.9	15.8
Ethanol	0.79	29.7	23.6	26.8	21.3
M15[4]	0.74	43.2	32.0	40.4	29.9
E20[4]	0.74	43.5	32.3	40.7	30.2
M85[4]	0.79	25.8	20.4	23.3	18.4
E90[4]	0.78	31.3	24.5	28.4	22.3
MTBE	0.74	38.1	28.2	35.3	26.2

(1) ±0.01; (2) ±0.1; (3) ±0.5; (4) Numbers refer to the volume percentage of alcohol in the blend (M=methanol blend, E=ethanol blend)

Table 12.5: Typical energy values for substitutes and blends with petrol

Fuel	C content[1]	CO_2 Emission factor	
	% mass	tCO_2/TJ	tC/TJ
Petrol	86	66.6	18.2
Methanol	38	62.4	17.0
Ethanol	52	64.2	17.5

1 Estimates of carbon content sourced from Bosch (1986)

Table 12.6: Typical values of CO_2 emission factor for alcohol fuels

value of around 113.

Data for petrol substitutes

Notwithstanding the trend towards flexible fuelling, data for particular blends are still presented in Table 12.5. Table 12.6 lists CO_2 emission factors for the alcohol fuels, in comparison with petrol.

Potential diesel substitutes (alcohols, vegetable oils and animal fats)

Alcohols

While the alcohols are attractive alternative fuels for petrol, they are inherently poor fuels for use in diesel engines. It is difficult to obtain diesel-like combustion with pure alcohol fuels in an unmodified engine because of their long ignition delay periods quantified by excessively low cetane numbers. Various ways of burning the alcohols, employing either partial or complete diesel substitution, are currently being investigated worldwide.

Vegetable oils and animal fats

These fuels generally have cetane numbers closely similar to diesel fuels, but exhibit similar combustion characteristics. High cloud points can cause problems in low ambient temperature conditions, but this can be quite easily overcome by the installation of a heating coil in the fuel tank.

The oils and fats may be used alone or in blends with diesel fuel in both direct and indirect fuelled engines. Their use is

becoming more widespread subject to feedstock availability and price.

Transesterification of the oils, using ethanol or methanol, reduces the viscosity to a level similar to diesel fuel and this helps to lower the combustion related problems. The influence of individual diesel engine designs when used with these fuels is considerable and whilst certain engines may perform satisfactorily others have reported failures after very short periods of operation.

Table 12.7 summarises specific gravity and net calorific data for a range of vegetable oils and animal fats.

Gas-to-liquids (GTL) and coal-to-liquids (CTL) Fuels

Overview

The production of synthetic fuels (so called 'synfuels') is an established technology with a history that dates back to the 1920s and coal-based plants. Modern technology, however, is very different from its original form which was aimed at the direct production of liquid fuels from coal and there is now a growing interest in the technologies as a means of converting natural gas, biomass and coal into high-value liquid fuels, including methanol, dimethyl ether, middle distillates and specialty chemicals and waxes. There is now a significant commercial experience in these technologies and considerable investigation worldwide into new projects based upon stranded gas resources and low-cost lignite coals.

In New Zealand, the gas-to-liquids plant at Motunui, which used the Mobil proprietary ZSM5 catalyst technology for the conversion of methanol to petrol, was one of the first plants of the modern

		NCV	
Fuel	**Specific Gravity[1]**	**MJ/kg[2]**	**MJ/l[3]**
Diesel	0.83	43.0	35.8
Castor oil	0.96	35.2	33.8
Linseed oil	0.93	39.5	36.7
Peanut oil	0.92	37.0	34.1
Rape seed oil (RSO)	0.92	37.6	34.5
Methyl esters of RSO	0.89	39.1	34.6
Ethyl esters of RSO	0.88	41.0	35.9
Safflower oil	0.91	39.5	36.1
Soybean oil	0.92	36.9	34.1
Tallow (molten)	0.89	38.8	34.7
Methyl esters of tallow	0.88	40.4	35.4
Ethyl esters of tallow	0.87	41.7	36.2
Butyl esters of tallow	0.87	41.2	35.9

1 ±0.01; 2 ±0.20; 3 ±0.50

Table 12.7: Typical data for specific gravity and net calorific value for potential diesel substitutes (Sources: Wickramanayake,1981; Sims et al.)

era. This plant produced merchantable grade petrol compatible in all respects with the New Zealand petrol specification, but low international oil prices led to its decommissioning in the late 1990s. More recent advances in Fisher-Tropsch (F-T) catalytic conversion technology that can convert syngas directly into middle distillate products (diesel and jet fuel) has seen this technology emerge as the preferred conversion option.

Synthesis of liquid fuels from coal or gas

There are two broad technology streams for the conversion of Coal to Liquids (CTL). The direct conversion process takes pulverised coal, which is mixed with oil and hydrogen under high pressure and heat to directly convert the coal into a syncrude suitable for further refining into conventional transport fuel products. The alternative indirect route subjects the coal feed to gasification in a reduced oxygen atmosphere, again at pressure and temperature, to produce synthesis gas (a mixture of carbon monoxide and hydrogen) for subsequent down-stream F-T conversion into liquid fuels.

This route is analogous to the Gas to Liquids (GTL) process that converts natural gas and oxygen feed via a partial oxidation (reforming) step to produce synthesis gas. The subsequent F-T synthesis involves the conversion of the hydrogen and carbon monoxide into long-chain paraffins, light olefins, high molecular weight waxes and water. The final product range is dependent on the operating conditions selected, and the design catalyst selectivity. The GTL chemistry is set out in Figure 12.2.

GTL diesel has a number of unique characteristics that differentiate it from conventional diesel. It has a cetane number in excess of 70, almost zero sulphur and aromatics, good cold flow characteristics, and it is ultra-pure by even the most stringent standards. It is anticipated that, with legislation progressively tightening diesel quality, GTL fuels will be a sought-after blending component with which to upgrade conventional refinery products.

GTL naphtha is the primary GTL Fuel co-product, and is highly paraffinic, which makes it an ideal feed for cracking to ethylene. Ethylene crackers are able to process a range of light hydrocarbon feedstock, and a wide range of naphtha grades find their way into this market.

Physical and chemical properties[1]

GTL liquids are in essence a tailored mix of hydrocarbons with properties that will vary depending on composition and subsequent treatment. Typically the fuel will be deployed as a blend stock so as to maximize overall supply economics. The properties and positioning of the product will be specific to intended end-use markets.

Density

GTL fuel consists almost entirely of paraffins, with less than 1% (mass) aromatics, and consequently the density of the GTL fuel is lower than that of conventional crude oil derived diesel fuels (0.78 kg/l compared to 0.82-0.85 kg/l).

Energy content

The gross heating value of the GTL Fuel (47.1 MJ/kg) is 4% to 5% higher than that of a typical crude oil derived diesel fuel. Due to the low density, however, the

1 Taken from Sasol Chevron Consulting Ltd., Submission to the Australian Government Fuel Tax Enquiry, Sept. 2001.

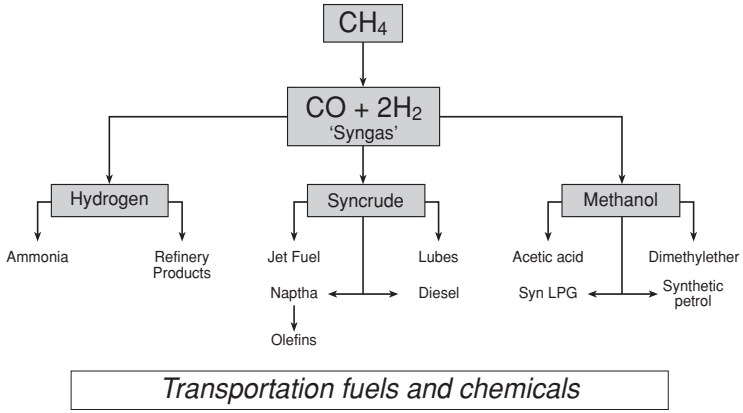

Figure 12.2: GTL production options (Source: Gaffney Cline and Associates, Review of a Gas to Liquids Industry for Australia, DISR, Australia)

volumetric energy content of GTL Fuel is lower than conventional diesel.

Cetane number and cold flow characteristics

GTL Fuel has a cetane number in excess of 70, while retaining good cold flow properties (CFPP lower than -20°C).

Sulphur content

As the Fischer-Tropsch synthesis catalyst is poisoned by sulphur, sulphur components in the synthesis gas are reduced to very low levels and, as a result, the sulphur content of the GTL fuel is less than 5 ppm.

Polar compounds

GTL fuel contains essentially zero oxygenates.

Thermal stability

Thermal stability, as determined by the Octel F21-61 test procedure (180 minutes at 150°C), is very good. The reflectance rating of 99.1% far exceeds the minimum limit of 80% proposed for the US 'Premium Diesel' specification.

Lubricity

Lubricity in a conventional diesel fuel is derived from the presence of polar molecules (including hydrocarbon-based and sulphur-based compounds). As GTL fuels are essentially sulphur-free and free of polar molecules, unblended GTL fuel displays poorer lubricity properties than crude oil derived diesel fuels.

If GTL fuel were to be used neat, a lubricity improvement additive would be need. Adequate lubricity can be achieved with a relatively low level of additive.

Engine performance and fuel consumption

On a standard compression ignition (CI) engine, fuel consumption using GTL fuel is comparable to conventional diesel. Although the fuel has a lower density than conventional diesel, this is compensated by two factors:

- Energy density per unit mass of GTL

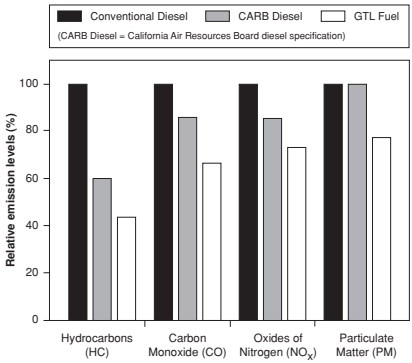

Figure 12.3: Heavy duty emissions with GTL Fuel (1991 Detroit Diesel Corporation (DDC) engine)

fuel is higher than that of conventional diesel, therefore a lower mass of fuel is required for the same energy output.

- Most CI engines are not able to operate at maximum efficiency due to emissions limitations. Because of the emissions benefits associated with combustion of GTL fuel, it is possible to operate under a more efficient control strategy with the use of this fuel.

An engine specifically designed to exploit the benefits of the higher cetane number and other characteristics of GTL fuel is expected to achieve a performance advantage over conventional modes. These effects are not fully quantified.

Emissions – compression ignition (diesel) engines

CI engines emit a range of pollutants, the two most important being oxides of nitrogen (NOx) and particulate matter (PM). GTL fuel has been tested in a number of programmes to evaluate emissions performance in compression ignition engines. Figure 12.3 shows exhaust emissions of GTL fuel compared with a typical US diesel fuel. The test was based on the US FTP cycle, using a 1991 Detroit Diesel engine. These tests indicate that GTL fuels exhibit significant emissions benefits.

Gaseous fuels

Character of the resource

Gaseous fuels come from a wide variety of sources. While natural gas is by far the most significant resource for gaseous fuels, this has not always been so. In New Zealand until the 1970s, gaseous fuel was Manufactured Town Gas. Although this commodity is no longer produced, data on it are included in this handbook for the purposes of historical analysis.

In addition to manufactured gas, three other types of gaseous fuel have been in use in New Zealand for some time, albeit in relatively small quantities. Acetylene and hydrogen are both fuel gases used in specialist industrial applications. However, hydrogen is viewed in some quarters as a prospective transport fuel for the future. Biogas comes from the anaerobic fermentation of organic materials, and Producer Gas from the gasification of organic materials. Also the possibility exists for harvesting coalbed methane.

Industrial fuel gases

Character of the commodities

Hydrogen and acetylene are two gases manufactured for combustion purposes. Hydrogen is stored in cylinders at ambient temperature and about 14 MPa pressure. Acetylene, dissolved in acetone, is stored in cylinders at ambient temperature and up to 1.5 MPa pressure.

Both gases are sold on the basis of gas volumes at atmospheric pressure and 15˚C.

Hydrogen

Sources of hydrogen

Hydrogen has the potential to become an attractive alternative fuel as its clean burning properties could help combat atmospheric pollution caused by the combustion of fossil fuels. Current large-scale manufacture of hydrogen is from fossil fuels, involving the release of carbon dioxide gas. If hydrogen is to be manufactured in the future, free of carbon dioxide emissions, it can be produced electrolytically from water, using hydro power, wind power, photovoltaic solar power or thermal solar power. Feasibility studies and demonstration plants are currently being investigated worldwide.

Hydrogen for transport

The greatest potential use for hydrogen is as a transport fuel. There are however two major problem areas involving the combustion of hydrogen in an engine and the storage of hydrogen in a vehicle.

The minimum ignition energy of hydrogen-air mixtures is an order of magnitude lower than that of petrol or CNG. Hence hot spots within an engine cylinder, or residual exhaust gases are likely to cause lightback and/or pre-ignition. This problem may be overcome by employing a well-designed mixture formation system.

The only pollutants from an engine operating on hydrogen are the oxides of nitrogen. Operating at lean air-fuel ratios or burning the fuel in a similar manner to diesel operation will ensure low levels of these pollutants. The rotary (Wankel) engine has inherent design characteristics that suit hydrogen operation.

Storage methods

The main storage methods for hydrogen are high pressure gaseous storage, metal hydride storage, and as liquid hydrogen. Despite the disadvantage of high cost for liquefaction, liquid hydrogen is the only method that provides a sufficiently high energy density for an acceptable storage volume. It has the added advantage that little energy is required to compress liquid hydrogen to the pressures necessary for high pressure gaseous injection.

Product	GCV MJ/m^3	NCV MJ/m^3
Hydrogen	11.9	10.1
Acetylene	54.4	52.6
Town gas	16.8	15.1
Producer gas	4.8	4.4
Methane	37.7	34.0

Table 12.8: Typical calorific values for hydrogen, acetylene, methane, town and producer gases at 15˚C and 101.325 kPa (absolute) pressure.

Manufactured town gas

Character of the commodity

Manufactured town gas used to be the single gaseous product retailed from manufacturing gas companies. Since its energy content was very closely specified, it was usually the blended product of several gases produced within the gas works from a variety of raw materials.

In coal gasification-oriented operations (once typical in throughout New Zealand) the bulk of manufactured town gas was derived from coal gas. This was often blended with other gas in order to

maintain the required calorific rating as well as to boost supplies. Sometimes supplies were made up with production of carburetted water gas and reformer gas. In reformer-type operations (once common in the North Island) manufactured town gas was derived from reformer gas using light distillate feedstock (gas naphtha) or natural petrol.

Calorific values for manufactured town gas are shown in Table 12.8.

Producer Gas

Character of the commodity

Any plant material capable of conversion to coarse charcoal within a gasifier makes suitable fuel for gasification. Although plant wastes can be used, wood is the most common feedstock. A typical analysis (% volume) of producer gas is:

20% carbon monoxide
19% hydrogen
1% methane
9% carbon dioxide
51% nitrogen

Calorific values

Producer gas from wood may vary in calorific value from 4.1 to 6.3 MJ/m^3. However typical data for practical purposes are:

Gas density (kg/m^3)	1.09
GCV (MJ/m^3)	4.8
NCV (MJ/m^3)	4.4

Coalbed Methane

Character of the resource

The occurrence of coalbed gases, mainly methane, has been considered a hazard in New Zealand coal mines and there have been several major explosions involving this gas mixture. Only in recent years has attention been turned to the potential for coalbed methane (CBM) to be tapped as a commercial energy source.

In New Zealand, coalbed gas most commonly comprises methane with small amounts of ethane. Available gas composition analyses suggest that it is rare to encounter more than a trace of other gases. Data for methane is given in Tables 4.1 and 4.2 (page 20).

Gas content of coals

Exploration and production of coalbed methane in New Zealand is in its infancy. Production is on a relatively small scale in a small number of locations in Otago/Southland and the Waikato.

Some data is available on the gas content of New Zealand coals. Gas content varies with coal rank. It can also be influenced by the geological structure within a coal deposit, with thick lenticular seams providing the potential for significant gas reserves. Estimates of likely gas-bearing capacities (m^3/tonne of in-ground coal) have been made for three coalfields, as follows:

Huntly coalfield	1-2
Greymouth coalfield	9-13
Aratika coalfield	3-8

Gas Hydrates

Gas hydrates are a substance in which molecules of water form a lattice that encloses molecules of methane gas. They are found in arctic permafrost or below the seabed and, in New Zealand, exist as a void-filling clathrate within sediments along New Zealand's deep-water continental margins (at water depths greater than about 800 m).

There is now general agreement that hydrate deposits serve as one of the largest storehouses of organic carbon on the planet, probably exceeding the amount remaining in all the world's oil, natural gas and coal deposits combined.

New Zealand has enormous gas hydrate reserves. The East Coast margin is considered one of the single largest gas hydrate provinces in the world, with an estimated area of about 50,000 km^2, an estimated volume of gas hydrate of at least 228.5 km^3, and about 23 Tm^3 of recoverable reserves[2]. Economically viable reserves may be greater than 1.1 Tm^3 (12 times larger than the Maui gas field).

The utilisation of gas hydrates as an energy resource in a safe and environmentally acceptable way is at present a major focus of several nations (Japan, US, India and others). Although the technology for production of natural gas from hydrates is at present in the developmental stage, transportation, storage and generation technologies are the same as for natural gas, eg:

- Deep offshore rigs.
- Offshore/onshore production.
- LNG import/export/storage.
- Gas plant.
- Gas Post treatment.
- Compression.
- Fischer-Tropsch syngas production.

Gas hydrates have the potential to provide New Zealand with a secure energy supply for both electricity generation and as a transport fuel. However, the technology for recovery of gas hydrates is by no means established, and the energetics of recovery are expensive.

2 Pecher, I A and Henrys, S A, 2003. *Potential Gas Reserves in Gas Hydrate Sweet Spots on the Hikurangi Margin, New Zealand*, Report v2003/23, Institute of Geological & Nuclear Sciences

13 Electricity

Resource base

Electricity is not an energy resource in itself, but is a means of transmission of energy. Because there is no simple inexpensive way of storing very large quantities of electricity it must be used as produced (or conversely produced as it is required) It is therefore always necessary to consider several aspects of electricity use:

- the magnitude of the resource(s) – *Energy.*
- The means of conversion.
- The rate of conversion and transmission – *Power.*

Electricity is quite often designated 'primary' or 'secondary' according to its generating source. Where no fuel is required as a feedstock for generation, it is called primary electrical energy. This includes hydro, geothermal, wind and photovoltaic sources. Electricity that is derived from other primary fuels — coal, oil, gas, wood, refuse, crop residues, etc. — is termed secondary electrical energy.

Historically, electricity generation in New Zealand has been based almost exclusively on relatively large-scale power stations — hydro, geothermal, or fired by coal, oil or natural gas. Within the last decade or so alternative modes of generating electricity have emerged. These include electricity from windpower (see Section 10) and from municipal wastes, as well as electricity from on-site cogeneration in industry. Small-scale solar-based technology (photovoltaic) has been in use in specialist situations for some years, as has micro-hydro technology.

Nevertheless, over 90% of the electricity presently generated each year in New Zealand comes from relatively large-scale power stations operated by the five major generating companies. The balance is generated in smaller facilities jointly owned with distribution network operators or large industrial plants (e.g. milk processing plant).

The resource base can be quantified in terms of the stocks and flows of primary resources available, or in terms of the installed generating capacity of existing power stations. Data for all operating power stations as of 2007 are given in Tables 13.1 and 13.2.

Electricity units

All electricity at a given voltage has the same energy value, regardless of source. The most frequently used and universally accepted unit for quantifying electrical energy is the kilowatt-hour (kWh). In commercial transactions, one 'unit' of electricity is the same as one kWh. The metric equivalent of one kWh is 3.6 MJ. Other standard multiples of the kWh are the GWh and TWh.

Electrical energy and power

Units of electrical energy (kWh) should not be confused with units of electrical power (kW). Power is concerned with the rate at which energy is transformed or used. For example, 15 kWh of electrical energy is the amount of energy involved if generated or used at the rate of 5 kW for a continuous period of three hours.

Thermal equivalents

In national energy accounts, the practice

Location	Name	Type	Ownership	Installed Capacity (MW)
1	Ngawha	Geothermal	Top Energy	10
2	Greenmount/ Rosedale	Landfill gas	Mighty River Power	8
3	Southdown	Cogeneration	Mighty River Power	125 + 45
4	Otahuhu A	Diesel fueled gas turbine	Contact Energy	40
5	Otahuhu B	Combined cycle gas turbine	Contact Energy	380
6	Glenbrook	Cogeneration	Alinta	112
7	Huntly	Coal/gas	Genesis Power	972
	Huntly	Gas	Genesis Power	50
	Huntly	Gas combined cycle	Genesis Power	385
8	Te Rapa	Cogeneration	Contact Energy	44
9	Te Awamutu	Cogeneration	Contact Energy/Anchor	54
10	Karapiro	Hydro	Mighty River Power	96
11	Arapuni	Hydro	Mighty River Power	206
12	Waipapa	Hydro	Mighty River Power	54
13	Maraetai I	Hydro	Mighty River Power	180
14	Maraetai II	Hydro	Mighty River Power	180
15	Kinleith	Cogeneration	Genesis Power	40
16	Wheao	Hydro	TrustPower	26
17	Kaimai	Hydro	TrustPower	42
18	Edgecumbe	Cogeneration	Todd Energy	10
19	Aniwhenua	Hydro	Todd Energy	25
20	Kawerau (TO1 & TG2)	Geothermal	Todd Energy	2.5 & 3.8
21	Matahina	Hydro	TrustPower	72
22	Ohaaki [1]	Geothermal	Contact Energy	50
23	Ohakuri	Hydro	Mighty River Power	106
24	Atiamuri	Hydro	Mighty River Power	86
25	Whakamaru	Hydro	Mighty River Power	100
26	Rotokawa	Geothermal	Mighty River Power	33
27	Tauhara	Geothermal	Contact Energy	15
28	Aratiatia	Hydro	Mighty River Power	90
29	Hinemaimai	Hydro	TrustPower	7
30	Wairakei	Geothermal	Contact Energy	162
	Wairakei	Geothermal binary	Contact Energy	16
31	Poihipi	Geothermal	Contact Energy	55
32	Mokai	Geothermal	Tuaropaki Power/ Mighty River Power	55 + 30
33	Tokaanu	Hydro	Genesis Energy	240
34	Rangipo	Hydro	Genesis Energy	120
35	Waikaremoana	Hydro	Genesis Energy	142
36	Kuatau & Piriaka	Hydro	King Country Energy	6 & 1.5
37	Waiere & Mokauiti	Hydro	King Country Energy	4.5 &1.9
38	New Plymouth	Diesel	Contact Energy	300
39	Taranaki CC	Gas	Contact Energy	367
40	Mangorei	Hydro	TrustPower	5
41	Motukawa	Hydro	TrustPower	5
42	Kapuni	Cogeneration	Todd Energy	25
43	Kiwi Co-op	Cogeneration	Todd Energy	85
44	Patea	Hydro	TrustPower	31
45	Tararua	Wind	TrustPower	32 + 36 + 94
46	Mangahao	Hydro	Todd Energy	38
47	Te Apiti	Wind	Meridian Energy	91
48	Te Rere Hau	Wind	NZ Windfarms	2.5
49	Hau Nui	Wind	Genesis Energy	3.85 + 4.8
50	Silverstream	Landfill Gas	Mighty River Power	2.7
North Island total				**5605.05**

1 104 MW installed; derated to 50 MW

Table 13.1: Generating stations in the North Island

Location	Name	Type	Ownership	Installed capacity (MW)
51	Cobb	Hydro	Trustpower	32
52	Argyle & Wairau	Hydro	Trustpower	11
53	Waihopai	Hydro	Trustpower	2.5
53	Dillmans (3 stations)	Hydro	Trustpower	10.5
53	Kaniere & McKays	Hydro	Trustpower	1.5
54	Coleridge	Hydro	Trustpower	45
55	Highbank	Hydro	Trustpower	25
56	Opuha	Hydro	Alpine Energy	
57	Tekapo A	Hydro	Meridian Energy	25
58	Tekapo B	Hydro	Meridian Energy	160
59	Ohau A	Hydro	Meridian Energy	264
60	Ohau B	Hydro	Meridian Energy	212
61	Ohau C	Hydro	Meridian Energy	212
62	Benmore	Hydro	Meridian Energy	540
63	Aviemore	Hydro	Meridian Energy	220
64	Waitaki	Hydro	Meridian Energy	105
65	Clyde	Hydro	Contact Energy	432
66	Roxburgh	Hydro	Contact Energy	320
67	Central Otago	Hydro	Pioneer Generation	
68	Waipori (4 stations)	Hydro	Trustpower	81.2
69	Paerau & Patearoa	Hydro	Trustpower	12.3
70	Monowai	Hydro	Pioneer Generation	6.3
71	Manapouri	Hydro	Meridian Energy	850
72	Arnold	Hydro	Trustpower	3
73	Roaring Meg	Hydro	Pioneer Generation	3.8
74	Wye Creek	Hydro	Pioneer Generation	1.3
75	Fraser	Hydro	Pioneer Generation	2.5
76	Teviot	Hydro	Pioneer Generation	14.5
77	Falls	Hydro	Pioneer Generation	1.2
78	White Hill	Wind	Meridian Energy	60
South Island total				**3653.6**
Total for NZ				**9193.65**

Table 13.2: Generating stations in the South Island

has sometimes been adopted of expressing primary electricity quantities in terms of 'thermal equivalents'. In other words, primary electricity is counted in terms of the amount of fossil fuel that would have been required to generate it. In practice, this adjustment is made by multiplying the primary electricity quantities (expressed in PJ rather than GWh) by a factor of two to three, depending on the fuel and the conversion method.

Power station locations

Tables 13.1 and 13.2 list generating stations in the North and South Islands respectively. Generating station locations are shown in Figures 13.1 and 13.2 for the North and South Islands respectively.

For hydro stations, load factors are influenced by variations in annual rainfall for each catchment, as well as the operating constraints (see Tables 13.3 and 13.4). In general, load factors for North Island hydro stations (47%) are typically lower than for South Island hydro stations (59%) with the overall figure for the hydro system being 55%.

The New Zealand hydro system is predominantly 'run-of-river', that is, the water must be used to generate electricity as it flows down the river. The

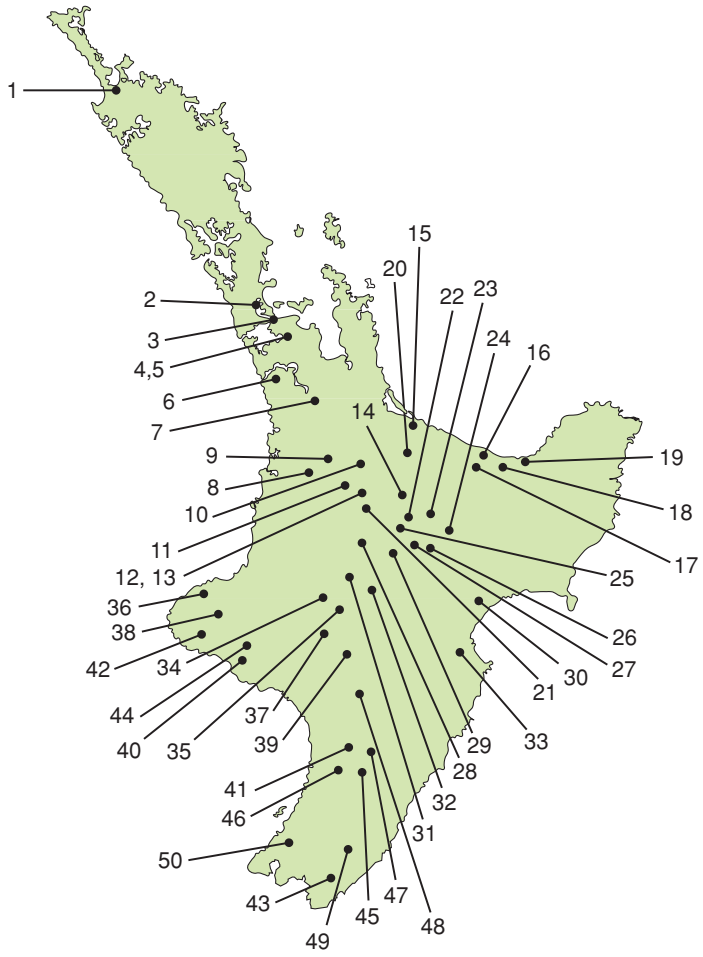

Figure 13.1: Location of generating stations in the North Island. Numbers correspond to locations given in Table 13.1.

storage capacity of the New Zealand's hydro reservoirs is relatively limited at around 3770 GWh, around a month of demand in the highest demand period and relatively low inflow months of July to September. Around 3110 GWh (82%) of this storage capacity is located in the South Island.

Fossil fuel-fired power stations are used mainly to provide for mid-load and peak electricity demand, or to boost supply when inflows and/or hydro storage levels are low. Thermal power station load factors are influenced by annual variation in climatic patterns with variation in rainfall affecting the output from hydro generation and variation in seasonal temperatures affecting demand for heating and cooling. Load factors for

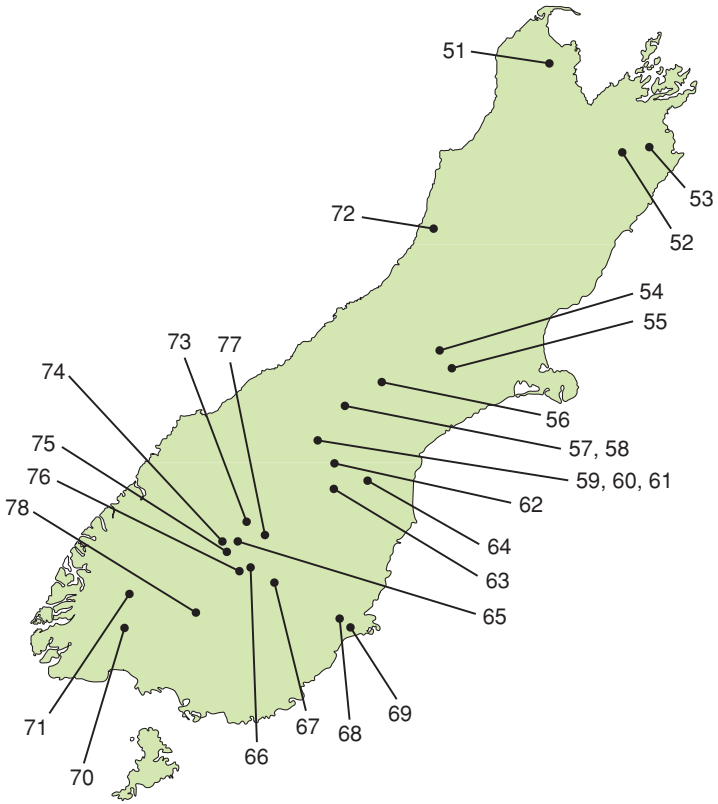

Figure 13.2: Location of generating stations in the South Island. Numbers correspond to locations given in Table 13.2.

thermal power stations can also be expected to rise progressively as the total load (national demand for electricity) increases, until it is displaced by additional new generation.

Tables 13.3 and 13.4 summarise hydro lakes and reservoir management data for the North and South Islands respectively.

Table 13.5 summarises current estimates of the potential hydro generating capacity from major catchments on the basis of existing power stations and their current installed capacities (Tables 13.1 and 13.2).

Estimates are given for mean-year conditions and dry-year conditions, where the latter is defined as having a one-in-twenty year probability of occurring. It is important to note that while mean-year estimates may be added together to yield a total potential hydro generating capacity, dry-year estimates are not additive. This is because dry years may occur in various catchments in different years.

DC link

Electricity is transmitted from the power stations to demand centres through the

Lake or Station	Lake area (km^2)	Catchment area (km^2)	Design flood (m)	Operating range (m)			
				Range	Max.	Min	Extreme min
Moawhango	4.660	602	853.44	14.00	851.00	837.00	835.75
Rangipo	0.024	216	822.70	3.10	818.40	815.30	814.50
Otamangakau	2.430		613.00	1.23	611.73	610.50	600.30
Te Whaiau	Canal fed		612.71	1.26	611.76	610.50	603.50
Rotoaira	15.800	117	565.25	0.61	564.65	564.04	561.90
Taupo	611.000	3510	357.39	1.25	357.10	355.85	
Aratiatia	0.550	115	339.05	1.20	337.80	336.60	336.00
Ohakuri	12.600	1575	289.10	0.94	286.94	286.00	285.10
Atiamuri	2.300	465	253.70	1.35	252.90	251.55	250.95
Whakamaru	7.400	240	227.60	1.55	226.50	224.95	224.55
Maraetai 1 & 2	5.000	690	189.70	1.65	189.00	187.35	187.35
Waipapa	1.600	245	129.10	0.60	128.10	127.50	125.05
Arapuni	9.100	260	113.30	1.05	111.00	109.95	109.00
Karapiro	7.700	875	54.10	1.90	52.90	51.00	50.60
Waikaremoana	54.000	347	617.50	3.00	610.80	607.80	607.20
Lake Kaitawa	0.061			2.60	480.20	477.60	477.60
Tuai		349					
Whakaremarino	0.298		275.25	1.40	275.10	273.70	273.40
Mangahao 1	0.440	87		11.90	357.90	364.00	360.66
Mangahao 2	0.192			9.37	342.37	333.00	333.00
Mangahao 3	0.073			10.37	342.37	332.00	332.00
Matahina	2.480	2844	76.80	3.05	76.20	73.15	71.63

Table 13.3: North Island lakes and reservoir management data

Lake or Station	Lake area (km^2)	Catchment area (km^2)	Design flood (m)	Operating range (m)			
				Range	Max.	Min	Extreme min
Tekapo A	87.90	1440	713.05	7.60	709.70	702.10	701.80
Tekapo B	Canal Fed		667.95	3.15	677.15	674.00	674.00
Lake Pukaki	169.00	1420	534.10	13.80	532.00	518.20	518.00
Lake Ohau	61.20	1135	524.15	0.30	519.75	519.45	519.45
Ohau A	Canal fed			1.10	517.50	516.40	
Lake Ruataniwha	4.90		460.00	0.30	458.80	458.50	458.00
Ohau B	Canal fed			0.60	458.80	458.20	
Ohau C	Canal fed			0.40	410.00	409.60	
Benmore	74.50	8500	362.60	0.95	361.45	360.50	355.25
Aviemore	28.80	1165	269.20	0.60	268.30	267.70	265.25
Waitaki	6.20	70	234.50	2.10	230.80	228.70	227.00
Lake Hawea	141.70	1384	349.05	8.00	346.00	338.00	330.00
Lake Wanaka	193.00	2575	279.80	1.95	278.30	276.35	
Lake Wakatipu	293.00	3067	310.95	1.05	310.65	309.60	
Clyde	25.00		195.10	1.00	194.50	193.50	
Roxburgh	5.90	8580	133.20	1.85	132.00	130.15	127.40
Lake Te Anau	352.00	3095		1.25	202.70	201.45	200.85
Lake Manapouri	141.00	5880		1.80	178060	176.80	175.85
Highbank	Canal fed		338.55	0.55	336.45	335.90	335.90
Coleridge	36.00	974	509.60	3.95	509.30	505.35	505.35
Cobb	2.10	69	810.75	13.70	807.70	794.00	788.20
Arnold	Run-of-river		80.16	0.91	79.55	78.64	76.20

Table 13.4: South Island lakes and reservoir management data

Hydro catchments	Mean year (GWh)	Dry year[1] (GWh)
North Island:		
Rangipo[2]	979	806
Tokaanu[2]	1613	1332
Waikato (total)[2]	3308	2683
Waikaremoana	507	327
Matahina	311	234
South Island:		
Waitaki tributary inflows	561	439
Ohau inflows	1870	1523
Pukaki inflows	3008	2383
Tekapo inflows	2923	2313
Roxburgh	1737	916
Manapouri/ Te Anau	5043	3951
Cobb	232	147
Coleridge	214	157

1 One in 20 year occurrence; estimates for individual catchments are not additive
2 Rangipo, Tokaanu and Waikato total include the appropriate diversions

Table 13.5: Potential hydro generating capacity from major catchments given existing power stations

high voltage transmission system owned and operated by TransPower New Zealand Ltd. Figures 13.3 and 13.4 show the high voltage network for the North and South Islands respectively.

Electricity is transferred between the North Island and the South Island by means of the DC link, of which the Cook Strait cables are an integral part. Electricity can be transmitted in either direction and the maximum operational capacity of the DC link is normally 1100 MW in the northward direction and 600 MW southward.

Terminology

Availability factor: The time when a generating unit is available for service (i.e. total time less planned and forced outage time), expressed as a percentage of total time.

Base load: A level of electrical power that is demanded on a continuous basis over a specified period.

Capacity or plant utilisation factor: The ratio of actual energy to total energy possible supplied over a period, usually a year. For example: a turbine with a rated capacity of 1 MW and operating with a capacity factor of 40%, will generate 1 MW x 0.4 x 8,760 h = 3,504 MWh annually (note that 8,760 is the number of hours in a year).

Dry hydrological year: Normally taken as the lowest mean annual flow to be expected at a station or site over a twenty year period. Again calculated from the hydrological records for that station or site.

Geothermal Generation: Geothermal power stations use energy derived from naturally occurring underground heat. Hot water is brought from the underground reservoir to the surface through wells, and is flashed to steam in special vessels by release of pressure. The steam is separated from the liquid and fed to a turbine. Spent geothermal fluid is injected back into peripheral parts of the reservoir to help maintain reservoir pressure.

Hydro Generation: Hydroelectric stations use the potential energy of water stored in lakes by a dam. When the water from the dam is released, gravity causes it to flow down into the power station, where the potential energy is converted into kinetic energy by turbines.

Installed capacity: The 'in-situ maximum' rating, usually expressed in megawatts (MW). It takes into account any permanent up or down rating.

Line losses: Losses incurred in the

Figure 13.3: North Island high voltage network (Source: Transpower)

transmission of electricity to bulk and retail consumers.

Load: The total power used or supplied to a defined block (e.g. a customer) integrated over a period (usually half an hour). Thus the national maximum load is the maximum energy generated or consumed in any half-hour of the year.

Figure 13.4: Sorth Island high voltage network (Source: Transpower)

Load factor: The ratio of average to maximum power demand over a period, usually a year, expressed as a percentage.

Maximum Control Level: The water level of a hydroelectric reservoir or storage lake above which the lake cannot be raised except under defined flood conditions given by the water right.

Mean hydrological year: The mean annual flow at a station or site, as determined by hydrological records for that station or site.

Minimum Control Level: The water level

of a hydroelectric reservoir or storage lake below which the lake cannot be lowered for operating purposes as defined by the water right.

Operating Range: The range in lake level between the minimum control level and maximum control level over which a hydro-electric reservoir or storage lake may be legally operated.

River Flows: The mean rate of water flowing down a river past a certain point over a period of time. Expressed in cubic metres per second (cumecs) or in litres per second.

Thermal Generation: Thermal power stations burn gas and/or coal to produce steam in a boiler, which then turns blades in a turbine. The blades are fixed to a shaft, which drives a generator and produces electricity. When the steam has passed through the turbines, it is cooled and recycled back to the boiler.

14 Energy Demand & Efficiency

Introduction

Over time the concept of energy efficiency has moved beyond a purely technical consideration of the ratio of energy output/energy input to a broader concept of the benefits provided by using energy more efficiently. The Energy Efficiency and Conservation Act 2000 defines energy efficiency as *"...a change to energy use that results in an increase in net benefits per unit of energy"*.

It's a simple concept, but extremely deceptive. The outcomes possible from improved energy efficiency can be expressed in a variety of ways:

- Increase benefits while keeping energy use constant.
- Keep benefits constant while decreasing energy use.
- Increase benefits *and* increase energy use (so long as Δbenefits › Δenergy use)
- Increase benefits and decrease energy use.
- Decrease benefits *and* decrease energy use (so long as Δbenefits ‹ Δenergy use).[1]

By the definition above, all gains in energy efficiency are good, but pursuing energy efficiency improvements *per se* as a public policy goal is problematic unless the outcomes to be achieved are very clear. Not only can there be co-benefits, there can also be hidden costs that are not well understood.

The ongoing development of technology and increasing energy prices mean that new, more efficient technologies constantly become available. This means that there is generally a potential to improve the efficiency with which we use energy to support various aspects of our lifestyles and industrial activities. Realising that potential requires the replacement of existing technologies at the end of their life with more efficient technologies. It is often also cost efficient to replace existing technologies ahead of their expected lifetime, or before they have worn out completely. Also, retrofit options can be available.

Potentials are typically quantified at three levels:

Technical potential – assumes the replacement of existing technologies with the most efficient option currently available; replacing our existing car fleet with hybrid cars would be an example.

Economic potential – this is a subset of technical potential; it assumes the replacement of energy-using technologies in all situations that achieve a given economic return; realising the efficiencies from a range of upgrades in a sector or industry with a payback of less than, say, three years is an example.

Market potential **–** this is a further subset describing the extent of technology replacement likely to be achieved by market actions; the energy efficiency improvements resulting from the growing (unsubsidised) sales of heat pumps is an example of market potential.

Realising potentials is constrained by behavioural, technological, economic and takeback constraints. Only recently have

1 McChesney, Smith and Baines, 2006, *The Impact on Housing Energy Efficiency of Market Prices, Incentives and Regulatory Requirements*, CHRANZ.

the complex interaction of factors that alter energy efficiency potentials started to be assessed. As an example, the energy savings potential from improvements in lighting efficiency will depend on the heating/cooling requirements of the particular building. Domestic dwellings usually require heating (particularly when lighting is simultaneously needed) so that some the energy benefit from efficient lighting will be offset by increased heating. In commercial buildings that usually require cooling, the energy by savings from efficient lighting will be enhanced by the reduced need for cooling.

Ensuring insulation and heating are optimised is important if the full value of other savings is to be realised. Conversely lighting efficiency improvements in large commercial buildings will provide something like a 33% increase from gross savings as the air conditioning systems are typically constantly removing heat and face a reduction in operation if lighting efficiency is improved.

Developing cost effective interventions around the above constraints is the art and science of successful energy efficiency adoption. The key to this is in understanding the nature and scale of the energy efficiency opportunities. Activities such as monitoring and targeting energy use, energy audits and energy bill reconciliation are used to assess the energy efficiency opportunity. For information on these, see www.ema.org.nz

Takeback/Rebound

There are real limitations to potentials. Typically new energy technologies provide both service or productivity improvements as well as energy savings. Users of those technologies will vary the balance between savings and service improvements according to their needs and the degree to which they benefit from either outcome. A good example of this takeback effect occurs when a home is insulated; typically about two-thirds of the potential savings will not be taken as energy savings, but as an increase in delivered heat. This is not a loss of efficiency – rather it's a valuable outcome as the improved comfort addresses an unsatisfied need and may deliver more valuable outcomes in terms of health and welfare.

Rebound occurs when money saved from energy savings, or for that matter any type of savings, is spent on a new activity, which in turn requires new ongoing expenditure.

Energy efficiency is perhaps straight forward at a micro-economic level – its typically a direct function of the thermodynamics of the technology and can be explained by an engineering analysis of technology energy using characteristics.

At a sectoral or macro-economic level, energy efficiency is less easy to quantify. It is not energy intensity, and physical indices usually do not adequately explain the wealth effect of energy efficiency. In general, one must factor out economic growth, structural changes and external factors such as weather change.

In short, energy efficiency is a complex and wide-ranging subject. A comprehensive portrayal goes well beyond the scope of this Handbook. As such, the following data serves to illustrate energy demand and efficiency concepts, rather than attempting to proscribe what is or is not energy efficient.

Transport

This is an important sector for New

Zealand as enormous challenges are apparent when it is realised that:

- New Zealand imports all transport technologies and fuels at increasing cost.
- The vehicle fleet is aging.
- There are no easy large-scale substitutes for mobility options or fuel quality.
- New Zealand has high transport dependence as remote trading nation.
- Transport has low elasticities, high vehicle ownership, and low vehicle occupancy.

One measure of efficiency is energy consumption per distance travelled. Figure 14.1 suggests that the energy efficiency of the New Zealand light petrol fleet has increased somewhat in this decade. New laws prohibiting the importation of older used vehicles and labelling of vehicle fuel efficiencies will improve the figures further, as will higher fuel prices inclining consumers to owning smaller and more fuel efficient vehicles.

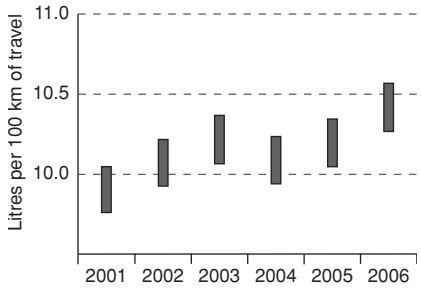

Figure 14.1: Light petrol fleet average fuel economy 2001-2006. Minimum and maximum estimates (Source: Ministry of Transport)

Table 14.1 provides comparative data for the different transport modes. Rail travel is the most energy efficient on a passenger-km basis. Yet the most energy intensive modes, cars and domestic air, comprise around 95% of both energy consumed and distance travelled. Not only are legacy issues, such as ownership and infrastructure, ignored in this illustration but so are issues such as time, consumer preference and convenience; not to mention others.

Table 14.2 offers comparative data for freight transport. Whilst road transport is not the most energy efficient mode for freight transport, it is, nevertheless, the dominant mode by which freight is moved.

Cars	Buses	Passenger Rail	Domestic Air	Total Travel
2.25	1.55	0.92	2.47	2.22

Table 14:1: Passenger energy intensity (MJ/p-km) by mode, 2006 (Source: EECA)

Road	Frieght Rail	Coastal Shipping	Overall Freight
3.15	0.44	0.37	2.38

Table 14:2: Freight energy intensity (MJ/t-km) by mode, 2006 (Source: EECA)

Industrial and commercial

Here, a selection of generic energy services are used to illustrate the efficiency of the various energy types. In keeping with the philosophy of the Handbook not to include economic data that will inevitably date, the 'economic efficiency' is generally not shown here. Instead, indicative energy prices may be found in publications such as the *Energy Data File*[2]. From 2010, a varying carbon

[2] Ministry of Economic Development, Energy Data File, June 2007, ISSN 1177-6676 or available online at www.med.govt.nz/energy/info, ISSN 1177-6684.

emission price will also impact on energy prices and choices. Unless otherwise indicated, information in this section is sourced from the New Zealand Centre for Advanced Engineering[3].

Figure 14.2 shows the energy required to produce one tonne of steam. The energy service demand of 2630 MJ is composed of the energy required to heat one tonne of water to boiling point and the energy required to completely evaporate the water. The comparisons shown describe the overall resource efficiency of delivering the energy service demand and takes into account delivery efficiency throughout the energy supply chain.

Figure 14.3 shows the energy required to produce one tonne of 75˚C hot water. The energy service demand in this instance is 252 MJ.

Figure 14.4 shows the energy required to keep a 100 m² office space air conditioned at an outside temperature of 30˚C for 8 hours. The energy service demand is 227 MJ. Typical technologies to provide the service would be gas absorption heat pumps or electric compressor heat pumps.

[3] New Zealand Centre for Advanced Engineering (CAENZ), *Understanding the Contribution of the Direct Use of Natural Gas to New Zealand's Future Energy Efficiency Objectives*, October 2007.

Residential

The HEEP breakdown of New Zealand household energy consumption by fuel type is given in Figure 14.5. Electricity use accounts for 69% of total residential national fuel use, followed by solid fuel at 20%, reticulated gas at 9% and bottled LPG at 2%. Heating oil is used in very few houses. The breakdown by location varies greatly, depending on the types of fuels that are used in houses, particularly for space heating. Many locations do not have a reticulated gas supply, and other fuels are used instead for space heating, cooking and water heating.

The HEEP breakdown of New Zealand household total energy consumption by end-use is given in Figure 14.6. The largest portion is space heating at 34%,

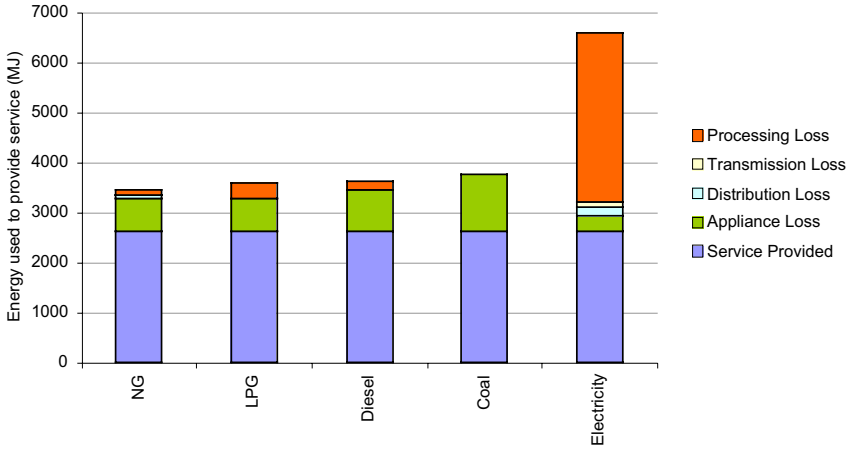

Figure 14.2: Commercial/Industrial steam – energy used to provide service

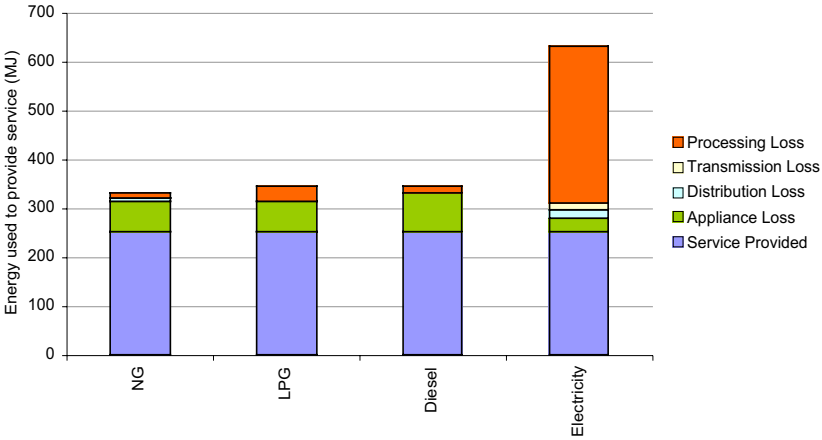

Figure 14.3: Commercial/Industrial hot water – energy used to provide service

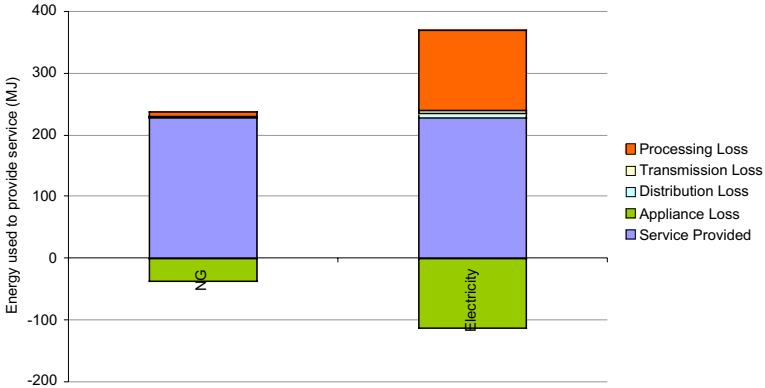

Figure 14.4: Commercial HVAC – energy used to provide service

then hot water at 29%, and refrigeration, other appliances, lighting, and range at around 10% each. The proportions vary by location, with less space heating energy used in warm and more in colder climates – up to 70% of energy use in the coldest climates.

Combining water and space heating, Figure 2 shows that on average that just under two-thirds (63%) of household energy use is for low grade heat (less than 100˚C).

Table 14.3 provides information on the highest and lowest 20% for total fuels and separately for electricity, gas, LPG and solid fuel. The total and the individual fuels demonstrate skewed distributions, with high users consuming far more per house than the smaller users. The ratio of the energy use per

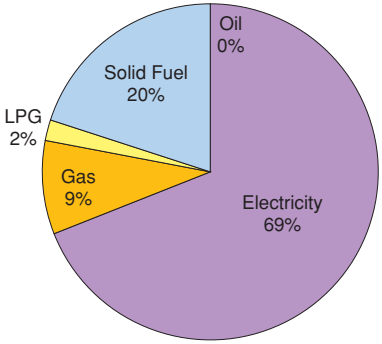

Figure 14.5: Total household energy use by fuel type (Source: BRANZ, 2006)

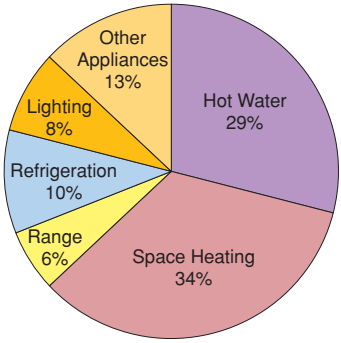

Figure 14.6: Total household energy use by end-use (Source: BRANZ, 2006)

Fuel	Bottom 20%		Top 20%		Ratio
	Use under:	% of energy	Use over:	% of energy	Top: Bottom
Electricity	4,860 kWh/yr	10%	10,380 kWh/yr	35%	2.1
Gas	2,580 kWh/yr	5%	9,900 kWh/yr	34%	3.8
Solid fuel heating	450 kWh/yr	1%	5,740 kWh/yr	57%	12.8
LPG heating	180 kWh/yr	3%	1,110 kWh/yr	50%	6.2
All fuels	**6,940 kWh/yr**	**9%**	**14,450 kWh/yr**	**36%**	**2.1**

Table 14.3: Fuel use – top and bottom 20% (Source: BRANZ, 2006)

house for the top 20% of houses to the bottom 20% of houses ranges from 2.1 to 12.8.

The data suggests that for a goal of reducing total household energy use (i.e. energy conservation), it is likely that the largest absolute reductions will come from the high energy using top 20% of houses. The typical 4 person family home tends to use about 10,000 kWh electricity per year.

The HEEP assessment of residential electricity use for all residences arrived at an average electricity usage of 7240 kWh per annum. Figure 14.7 provides a breakdown of electricity usage. There no simple relationship between the number of electrical appliances and either the total energy or peak power demand. The use of electrical appliances is a more important determinant of total energy use than the number.

NZ homes average about 120 m^2, which is between European (100 m^2) and American house (160 m^2) sizes.

New Zealand homes are under-heated by comparison to other nations. This is a combination of poor insulation; New Zealand has 960,000 pre-1978 homes built without insulation, a lack of effective and efficient heating systems, and behavioural patterns of tolerating indoor temperatures below World Health Organisation recommended levels for

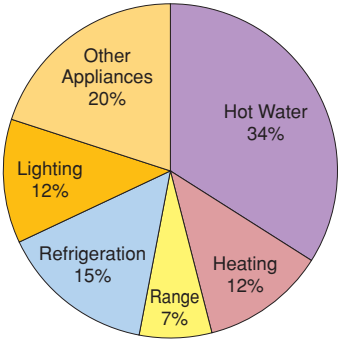

Figure 14.7: Household electricity usage (Source: BRANZ, 2006)

health of 16˚C.

Figure 14.8 shows the total energy demand across a range of technologies for supply of domestic dispersed space heating (unless otherwise indicated, information in this section is sourced from the New Zealand Centre for Advanced Engineering). The service is defined as the amount of energy required to heat a 25 m^2 lounge with a ceiling height of 2.4 m from 10˚C to 20˚C with some account taken of heat loss to the outside and heat gain from electronic equipment. The resulting energy service is calculated to be 18.4 MJ.

Here, as in many other areas of energy consumption, energy efficiency alone should not decide technology or appliance selection. Capital costs, energy costs and, increasingly, emissions costs, need to be considered. Heat pumps are becoming increasingly popular but it is not always or well understood that the power output of air-source heat pumps decrease significantly at outside temperatures below 7˚C. Unflued heating appliances are likely to release some toxic emissions. Small appliances may deliver uneven temperatures.

Figure 14.9 shows the total energy demand across a range of technologies for supply of domestic central space heating. The service is defined as the amount of energy required to heat a house from 10˚C to 20˚C and maintain this temperature for 3 hours at an outside temperature of 10˚C. The resulting energy service is made up of 35 MJ for heat up and 51 MJ for heat maintenance energy, a total of 87 MJ.

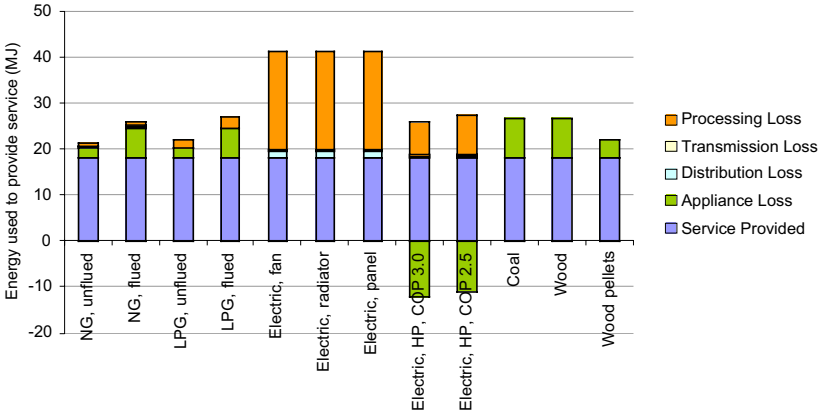

Figure 14.8: Domestic dispersed space heating – energy used to provide service

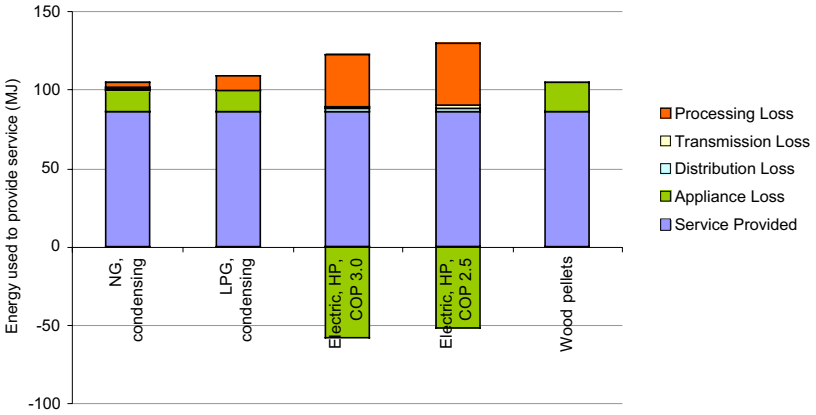

Figure 14.9: Domestic central space heating – energy used to provide service

Some technologies such as oil and coal fired appliances have been omitted since they are no longer preferred options for new installations.

Figure 14.10 shows the total energy demand for one example of domestic cooking. The service is defined as the amount of energy required to cook 500 g of spaghetti in 2 litres of water. The resulting energy service is calculated to be 1.1 MJ. Obviously, different cooking applications, particularly extending beyond boiling, such as baking or roasting, may result in quite different energy preferences.

Figure 14.11 shows the total energy demand for one example of domestic hot water use. The service is defined as a 5 minute shower, assuming a shower flow rate of 10 litres per minute, cold water supplied at 15˚C and a shower temperature of 40˚C. The resulting energy service

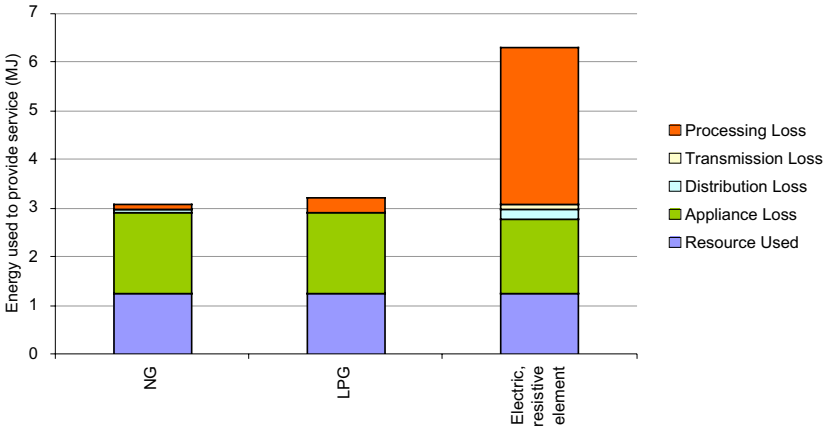

Figure 14.10: Domestic cooking – energy used to provide service

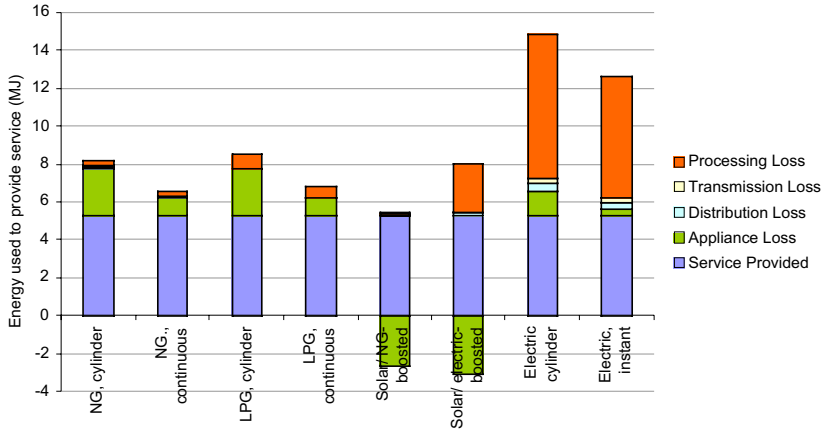

Figure 14.11: Domestic hot water – energy used to provide service

required is 5.4 MJ. From an energy perspective, a solar/gas-boosted system is best, and this conclusion follows through strongly when energy cost is considered, since solar is essentially free. However, this analysis does not consider capital costs.

Figure 14.12 summarises appliance efficiencies typically attributed for a range of domestic applications. The huge variability in some cases reflects appliance design, materials and costs.

Household appliances

Table 14.4 shows estimates of electricity use by appliance. The figures show which appliances are, on average, the most energy intensive, by way of energy demand and/or intensity of use. For example, refrigerators and the like are quite energy intensive because they are always on. In comparison, washing machines operate for many fewer hours on an annual basis. This information may be used as a guide as to which applications are more important based on

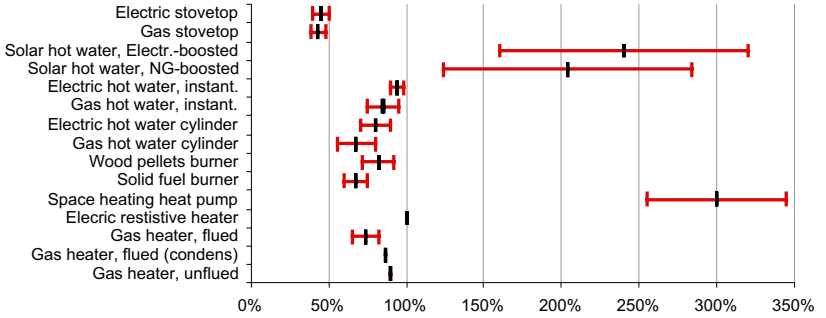

Figure 14.12: Range of technology efficiencies

energy efficiency considerations.

It should be noted that some modern heating devices (such as gas heaters and clothes driers) are designed to recover some of the latent heat of condensation of water and can therefore appear to have an abnormally high 'efficiency'.

Heat pumps

Heat pumps are different from other heating appliances, because heat is not generated from electricity or a fuel, but heat is extracted from one source (normally outside air or soil), raised in temperature level, and released where needed.

	kWh/year	Standard error
Computer/games	196	27
Dehumidifier	554	281
Dishwasher	211	28
Dryer	173	32
Elect blanket	49	9
Elect jug	157	12
Portable heater	71	64
Freezer	663	39
Fridge-Freezer	621	30
Heater	488	81
Iron	11	2
Large miscellaneous	116	57
Lighting (plug-in)	40	10
Microwave	78	5
Other climate control	289	105
Other cooking	19	6
Other entertainment	114	23
Rangehood	27	7
Refrigerator	367	62
Small miscellaneous	4	2
Spa	398	288
Toaster	20	3
TV	132	13
Vacuum cleaner	21	4
Washing machine	59	7

Table 14.4: Estimates of electricity use by appliances (Source: BRANZ)

As heat is not actually generated from the energy content of a fuel, heat pumps have apparent efficiencies in excess of 100%. The performance of heat pumps is usually denoted by the coefficient of performance (COP). This is the ratio of the energy delivered as heat to the energy input used to drive the device.

In contrast to efficiencies of combustion heating appliances or electric resistive heating, the COP is strongly temperature dependent. For example, as the temperature difference between the outside (source) temperature and the inside (delivery) temperature decreases, the COP of a heat pump increases.

In order to compare the relative efficiencies of different heat pump models, the Australian Minimum Energy Performance Standard requires that heat pump COPs be compared at an outside temperature of 7˚C. Such a test might give the typical results shown in Table 14.5.

COP at 7°C (rated)	*Estimated Performance in*		
	Auckland	Christchurch	Dunedin
3.0	COP 3.2	COP 2.6	COP 2.2
3.5	COP 3.6	COP 3.0	COP 2.5

Table 14.5: Heat pump COPs at various locations

The figures in Table 14.5 can now be directly compared with the efficiency of another appliance.

Regional data

Tables 14.6 to 14.9, based on the HEEP research, provide the estimates of the annual gross energy in kWh for the fuels and end-uses which were monitored in a significant number of houses. These are averages over all New Zealand houses – not the fuel use that would be found in a

house with that fuel and that end-use. Note that fuel oil is not separately included due to the small HEEP sample size.

Location	All fuels	SE	Electricity	SE	Gas	SE	LPG	SE	Solid fuel	SE
Overall	11,410	420	7,800	210	1,060	140	240	40	2,310	270
Auckland	10,660	520	7,970	360	1,870	370	90	30	720	190
Hamilton/Tauranga	10,750	840	7,270	780	1,780	570	120	60	1,580	580
Wellington	10,860	790	7,840	610	2,380	630	200	110	640	260
Christchurch	11,010	750	8,710	500	220	160	320	190	1,750	530
Dunedin/Invercargill	14,580	1,450	10,610	1,010	170	170	820	320	2,980	940
Clusters	11,740	810	7,300	340	530	160	270	60	3,620	550
Warm clusters	9,960	790	6,740	420	500	210	340	80	2,380	520
Cool clusters	13,780	1,170	7,950	490	560	240	190	80	5,050	790

Table 14.6: Average annual total energy use per house by fuel (Source: BRANZ)

Location	All fuels	SE	Electricity	SE	Gas	SE	Solid fuel	SE
Overall	3,260	100	2,440	80	660	90	150	40
Auckland	3,580	200	2,310	180	1,270	260	-	-
Hamilton/Tauranga	3,390	530	2,590	590	660	320	140	60
Wellington	4,610	420	2,350	300	2,240	550	30	20
Christchurch	2,960	210	2,710	210	140	140	110	40
Dunedin/Invercargill	3,100	280	2,840	310	-	-	250	160
Clusters	2,860	140	2,400	100	190	80	260	90
Warm clusters	2,700	170	2,270	100	280	130	150	110
Cool clusters	3,050	220	2,540	180	100	70	370	130

Table 14.7: Average annual hot water energy use per house by fuel (Source: BRANZ)

Location	All fuels	SE	Electricity	SE	Solid fuel	SE	Gas	SE	LPG	SE
Overall	3,820	350	920	190	2,150	250	520	110	240	40
Auckland	3,190	840	1,630	720	720	190	750	340	80	30
Hamilton/Tauranga	2,830	530	280	80	1,430	530	990	360	120	60
Wellington	2,630	730	780	600	610	250	1,230	400	200	110
Christchurch	3,010	690	950	350	1,640	520	90	90	320	190
Dunedin/Invercargill	6,810	910	3,130	420	2,720	820	140	140	820	320
Clusters	4,370	560	420	110	3,360	510	320	130	270	60
Warm clusters	3,080	480	290	140	2,230	450	220	160	340	80
Cool clusters	5,860	830	550	180	4,680	750	440	230	190	80

Table 14.8: Average annual space heating energy use per house by fuel (Source: BRANZ)

Location	All cooking	SE	Range	SE	Lighting	SE	Refrigeration	SE
Overall	900	60	630	50	910	90	1,120	70
Auckland	1,030	100	650	90	1,460	300	1,030	160
Hamilton/Tauranga	910	210	590	190	620	110	1,100	100
Wellington	1,090	340	800	340	880	250	1,220	260
Christchurch	990	160	700	140	530	130	800	170
Dunedin/Invercargill	970	150	740	110	1,550	150	720	280
Clusters	760	70	570	70	680	90	1,260	110
Warm clusters	840	110	620	110	580	110	1,470	140
Cool clusters	620	70	430	60	800	140	1,000	110

Table 14.9: Average annual energy use per house for selected end-uses (Source: BRANZ)

15 Energy Storage

Introduction

Energy storage plays a central role in all energy systems. In electric power systems, energy storage has two functions:

- to bridge a time gap between energy production and use; and
- to improve power quality. Energy storage is especially important if power sources are intermittent or production curves and demand curves are offset.

Apart from conventional electrical energy storage systems, other forms of energy storage include thermal storage, chemical storage, and mechanical energy storage. Generally, energy storage is expensive and all techniques are afflicted with significant losses.

Electrical energy storage

Electrical energy may be stored directly as electrical charges in capacitors or in magnetic fields in Superconducting Magnetic Energy Storage (SMES) systems. Batteries store electrical energy as chemical charges.

Capacitors and supercapacitors

Capacitors are used for various purposes in electronic circuits. Some electronic devices, such as cameras, use capacitors as intermediate batteries to store energy temporarily.

Supercapacitors or ultra capacitors have energy densities several orders of magnitude higher than standard capacitors. They are therefore suitable for storing significant amounts of energy. The main advantage of supercapacitors over batteries is their ability to store and release energy much faster, making them attractive for applications such as regenerative braking in automobiles. Batteries, on the other hand, have still higher energy densities. The position of capacitors versus batteries in terms of energy density and power density is shown in the Ragone chart in Figure 15.1.

Electrochemical storage – batteries

Batteries are the most cost effective and most common type of energy storage for portable devices. Batteries have relatively high charge-discharge efficiencies and high energy densities. Ranges for specific energy and power densities for different battery types are shown in Figure 15.1. Lead acid batteries are still the least-cost option for many large storage applications. For safety and maintenance reasons, mobile applications favour sealed lead acid batteries, while valve regulated lead acid batteries show better cost and performance for stationary applications[1].

Most batteries are heavy metal based and can pose an environmental hazard. New Zealand currently has no effective collection and recycling system in place.

A critical advantage of capacitors over batteries is their much longer lifetime (see Figure 15.1). While commercially available batteries last for up to 1000 cycles, supercapacitors have lifetimes in the range of one million cycles. Supercapacitors can have roundtrip efficiencies of around 95% or more.

1 Ribeiro, P F, 2001. "Energy Storage Systems for Advanced Power Applications", *Proceedings of the IEEE*, 98(12), pp 1744-1756.

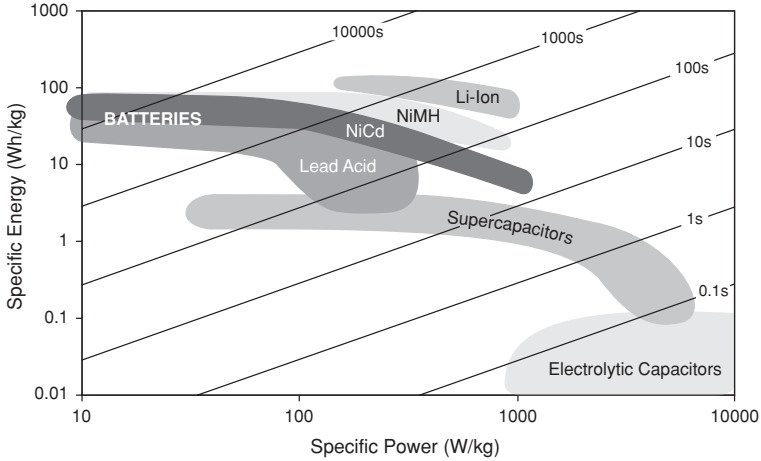

Figure 15.1: Ragone chart – specific energy versus specific power ranges for current technology (based on information from www.aktuelle-wochenschau.de)

Superconducting magnetic energy storage (SMES)

SMES devices store energy in magnetic fields which are produced by dc currents flowing through superconducting coils. SMES is a relatively new technology for energy storage. Advantages of the technology include fast response times and high charge-discharge efficiencies of over 95%[2]. While still comparatively expensive, SMES are becoming commercially available. Their greatest potential probably lies with power conditioning applications.

Chemical energy storage

Energy can be stored in chemical compounds. For example, biomass is a form of stored solar energy. Since biomass has already been covered in Chapter 8, this section considers other froms such as hydrogen, a chemical energy storage system that can be employed through technical processes.

Hydrogen is special among chemical energy carriers in that can be readily used as a fuel and is carbon free. One of the main attractions of hydrogen is that it can be produced by electrolysis from water using electricity as energy input. Hydrogen may be compressed or liquefied, stored in special tanks, and used in internal combustion engines or fuel cells. In recent years, there has been broad political promotion of a hydrogen economy.

However, a hydrogen economy is not feasible with today's commercial technologies and is one of the least efficient ways of using electricity. With efficient fuel cells, a hydrogen energy storage system could achieve roundtrip efficiencies of only 20% to 25%, ignoring losses on start up. The energy flow chart in Figure 15.2 compares the use of electricity for powering vehicles. In the case of a hydrogen car, 100kWh of initial

2 Ribeiro, P F, 2001. "Energy Storage Systems for Advanced Power Applications", *Proceedings of the IEEE*, 98(12), pp 1744-1756.

electric energy is reduced to 21 to 26kWh of useful mechanical energy (which is similar to petrol powered vehicles). In contrast, a battery powered electric vehicle recovers 69kWh of the initial 100kWh as useful energy; 3.5 times more efficient than the hydrogen case. The flowchart shows typical efficiencies of the hydrogen supply chain.

Kinetic energy storage

Flywheels

Flywheels store energy as rotational energy in a high speed rotor. When coupled to an electric motor/generator, flywheels can be used to operate as storage in power systems. There are two strategies to improve the energy capacity of flywheels: an increase in rotational speed for lighter flywheels or an increase in rotor mass, diameter and inertia. The latter type of heavier flywheels is commercially available as Uninterruptible Power Supply (UPS) devices. Flywheels have various applications in power conditioning as well as peak shaving. Since the 1940s flywheels have been used repeatedly, though unsuccessfully, in order to power various bus systems. Examples of failed flywheel bus systems include the Gyrobus system by Oerlikon (Swizerland), the flywheel buses in Léopoldsville in Zaïre, and in Ghent, Belgium.

Potential energy storage

Pumped storage

Pumped storage is a way of storing bulk energy in the form of potential energy of water. If the local geography allows,

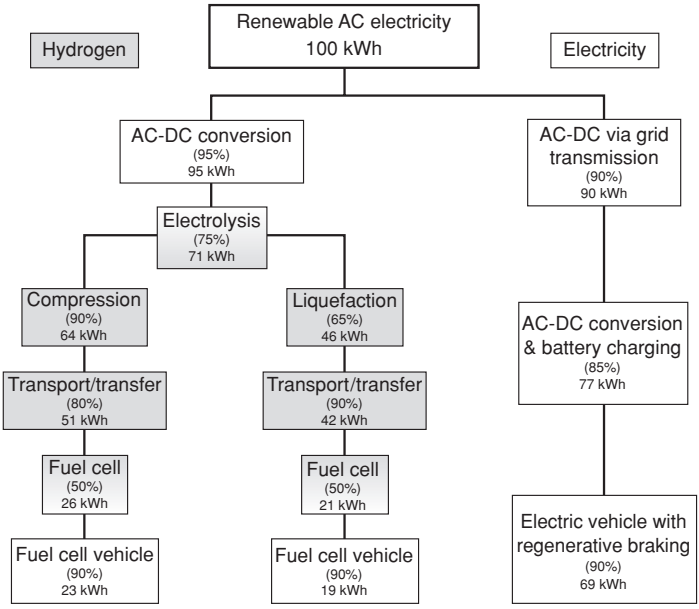

Figure 15.2: Useful transport energy derived from electricity (Source: Bossel, U, 2006. "Does a Hydrogen Economy Make Sense?" Proceedings of the IEEE, *2006, 94(10).*

pumped storage can be the most efficient and most cost effective way of storing large amounts of electric energy. Pumped storage systems use electricity to pump water from a lower to an upper reservoir, and produce electricity by releasing water from the upper reservoir to drive a hydro turbine. Pumped storage is scaleable and can be used in systems from a few kilowatts to several gigawatts. It is possible to use the same machine as pump and turbine. Often, pumped storage systems are part of conventional hydroelectric plants, and, depending on reservoir sizes, offer a means of strategic storage. Technical efficiencies are of the order of 70% to 85%, while larger plants have lower hydraulic resistance and are thus more efficient than smaller installations. Depending on reservoir size and local climate, there are additional losses through evaporation.

Worldwide there are about 100 major pumped storage installations. Despite New Zealand's high percentage of hydroelectric generation for the national grid, the reservoirs are relatively small. None of New Zealand's large hydro electric schemes offers pumped storage. Rather, the reservoirs are effectively used as short term storage by discharging them in times of high demand.

Springs

Springs are used for very small energy storage applications, such as watches.

Compressed air energy storage (CAES)

Compressing air as a form of stored energy is an old concept but is presently enjoying renewed interest. There are two categories of systems: Small systems for mobile applications, where air is stored in high pressure bottles such as steel LPG bottles. Large systems employ underground features as storage reservoirs, such as naturally occurring aquifers, depleted gas fields, solution-mined salt caverns, or mechanically formed reservoirs in rock formations[3]. Technical efficiencies of compressing or expanding air are in the order of 75%, resulting in a round trip efficiency of 55%.

Compressed air storage systems are suitable for potential bulk energy storage for load shifting. Whilst pumped hydro storage, batteries and fuel cells have some advantages, only compressed air energy storage has the storage capacity of pumped hydro, but with lower cost and less geographic restrictions[4].

An interesting potential application is the large-scale direct air compression by wind turbines for short-term bulk storage in order to mitigate the fluctuating nature of direct electrical wind power.

Heat Energy Storage

Storing thermal energy can be an attractive option for thermal end uses. Heat has been traditionally stored as sensible heat, for example in a thermos bottle, or as latent heat, such as in ice storage systems.

For sensible heat storage, the most important characteristic of the storage media is its heat capacity in kJ/kg/K. As the most widely used medium for heat storage, water has a high heat capacity combined with global availability and easy transportability. Water storage tanks are made from and insulated with a

3 Schoenung, S M and Burns, C, 1996. "Utility Energy Storage Applications Studies", *IEEE Transactions on Energy Conversion*, 11(3), pp 658-665.

4 Bullough, C, *et al.*, 2004. "Advanced Adiabatic Compressed Air Energy Storage for the Integration of Wind Energy", *Proceedings of the European Wind Energy Conference, EWEC*, 2004, London.

variety of materials. For large storage applications, underground aquifers have been used. Problems with evaporation or high water pressures can be avoided by using solid storage media such as sand or rocks. Storage in solid materials is particularly interesting for space heating applications, but also wherever high temperatures, up to 1000˚C or more, are required.

While sensible heat may be the simplest form of heat storage, latent heat has some advantages: heat storage can occur at a very small temperature range, and less storage is required for certain storage tasks. For example, the same amount of energy is required to transform 1kg of ice to water, as heating 1kg of water from a temperature of 0˚C to 70˚C. Phase change materials (PCMs) may undergo phase changes from solid-to-liquid, or liquid-to-gas. Few solid-to-solid phase change materials have attractive heats of fusions as well as practical phase change temperatures. Liquid-to-gas phase changes incur large volume changes and are therefore impractical; however, they are used commercially in steam accumulators. The highest potential is vested with solid-to-liquid phase changes. Some indicative materials and their respective heats of fusion and fusion temperatures are listed in Table 15.1.

A notable use of PCMs for energy stoarge was Solar Two, a large-scale, pilot solar-thermal pant operated in the Mojave Desert from 1995 to 1999. It used a 60% sodium nitrate: 40% potassium nitrate mixture as an energy storage medium.

A list of potential applications for PCMs for heat storage applications is given in Table 15.2.

Material	Transition Temperatures ˚C	Heat of fusion kJ/kg
Water	0	335
Glauber's Salt	32	348
Paraffin	20-60	140-280
Salt Hydrate	30-80	170-270

Table 15.1: Some latent heat storage materials and their temperature ranges (Source: Hasnain, S H, 1998. "Review on sustainable thermal energy storage technologies, Part I: heat storage materials and techniques", Energy Conversion and Management *39(11))*

Mode of implementation PCMs technology	Load Target	Objective	Sector
Distributed PCM storage in gypsum boards	Space heating and air conditioning	Load shifting and conservation	All
Electrical heating units with PCM storage	Space heating	Load shifting and conservation	Residential, commercial and institutional
Heat and cold PCM storage in air ducts	Space heating and air conditioning	Load shifting	Commercial, institutional and industrial
PCM air preheaters for heat pumps	Space heating	Load shifting and conservation	Residential, commercial and institutional
Curtain walls with PCM system	Space heating	Conservation	Commercial, institutional and industrial
Water heater with PCM storage	Water heating	Load shifting	Residential, commercial and institutional

Table 15.2: Potential implementations of thermal storage by phase change materials (PCMs) (Source: Hasnain, S H, 1998. "Review on sustainable thermal energy storage technologies, Part I: heat storage materials and techniques", Energy Conversion and Management *39(11))*

16 General Physical Conversion Factors

SI units of measurement

As with the conversion factors presented in Section 2, the emphasis here is on highlighting SI units in each case.

Tables of physical conversion factors are given for temperature (Table 16.1), length (Table 16.2), area (Table 16.3), volume (Table 16.4), mass (Table 16.5), pressure (Table 16.6), velocity (Table 16.7), flowrate (volumetric) (Table 16.8) and density (Table 16.9), and liquid specific gravity (Tables 16.10 and 16.11).

Temperature

The various units used in the measurement of temperature are defined as follows:

- Celsius (also known as Centigrade), a scale on which the freezing point of water is 0 degrees, and the boiling point of water 100 degrees (at normal atmospheric pressure).
- Fahrenheit, a scale on which the freezing point of water is 32 degrees and the boiling point of water is 212 degrees (at normal atmospheric pressure).
- Kelvin is the absolute scale (and the International Standard [SI] measure of temperature), whereby absolute zero at -273.15°C is equal to 0K (note that no degree symbol is used in SI notation). One Kelvin is the same temperature increment as one degree Celsius (so 273.15 K = 0°C).
- Rankine is the absolute Fahrenheit scale, whereby absolute zero at -459.69°F is equal to 0°R.

The general conversion factor is that 1.8 Rankine or Fahrenheit degrees = 1 degree Celsius or 1 K.

Mass/volume interrelationships

Because liquid fuels are sometimes measured by weight and sometimes by volume, it is often necessary to translate data from one basis to the other. Interrelationships of mass and volume are determined precisely by specific gravity. Within the metric system, conversions can be made by multiplying volume by specific gravity, or by dividing mass by specific gravity.

Specific Gravity is the ratio of the mass of a body to the mass of an equal volume of water at some specified temperature. For gases, the specific gravity is often taken as the ratio of the mass of a quantity of gas at a specified temperature and pressure to the mass of the same volume of air at the same temperature and pressure.

Since volumes change with changing temperature and pressure, data on specific gravity are usually accompanied by reference to the temperature and pressure at which the relationship is measured. In the case of petroleum and its products, the relationship is usually measured at 15° Celsius (59°F) or 60° Fahrenheit (15.6°C) and at standard atmospheric pressure. Specific gravity is often quoted as a percentage. Thus a stated specific gravity of 85 means an actual specific gravity of 0.85.

API (American Petroleum Institute) Gravity is commonly used overseas for petroleum products and is precisely related to

specific gravity (Sp. Gr.) by the following formula:

API grav. = [141.5/Sp.Gr.(60°F)] – 131.5

Specific gravity and API gravity move in opposite directions. That is to say, API gravity moves in the same direction as energy content per unit mass, which rises in petroleum products from 43.0 MJ/kg at 10° API to 49.2 MJ/kg at 125° API. Specific gravity moves in the same direction as energy content per unit volume; e.g. from 4330 MJ/barrel at 0.55 Sp.Gr., it increases to 6840 MJ/barrel at a specific gravity of 1.00.

In other systems, and between systems, conversions of mass to volume can be made using factors given in Table 16.10, while conversions of volume to mass are given in Table 16.11.

To convert to: / from:	K	°C	°F	°R
	multiply by			
Degrees K	1	K - 273.2	1.8(K) - 459.7	1.8(K)
Degrees C	°C + 273.2	1	1.8(°C) + 32	1.8(°C) + 459.7
Degrees F	(°F + 459.7) / 1.8	(°F - 32) / 1.8	1	°F + 459.7
Degrees R	°R / 1.8	(°R - 491.7) / 1.8	°R - 459.7	1

Table 16.1: Temperature conversion factors

To convert to: / from:	m	mm	km	in	ft	yd	mi	inmi
	multiply by							
metres (m)	1	1000	0.001	39.37	3.281	1.0936133	6.214 xl0^{-4}	5.400 xl0^{-4}
millimetres (mm)	0.001	1	1 xl0^{-6}	3,937 xl0^{-2}	3.281 xl0^{-3}	1.094 xl0^{-3}	6.214 xl0^{-7}	5.400 xl0^{-7}
kilometres (km)	1000	l x10^{6}	1	3.937 xl0^{4}	3.281 xl0^{3}	1.094 xl0^{3}	0.621	0.540
inches (in)	2.540 xl0^{-2}	25.4	2.540 xl0^{-5}	1	8.333 xl0^{-2}	2.778 xl0^{-2}	1.578 xl0^{-5}	1.371 xl0^{-5}
feet (ft)	0.3048	304.8	3.048 xl0^{-4}	12	1	0.333	1.894 xl0^{-4}	1.646 xl0^{-4}
yards (yd)	0.9144	914.4	9.144 xl0^{-4}	36	3	1	5.682 xl0^{-4}	4.937 xl0^{-4}
miles (mi)	1609.3	1.609 xl0^{6}	1.609	63360	5280	1760	1	0.8690
international nautical miles (inmi)	1852.0	1.852 xl0^{6}	1.852	72913	6076	2025	1.1507823	1
fathom	1.829	1829	1.829 xl0^{-3}	72	6	2	1.136 xl0^{-3}	9.875 xl0^{-4}
chain	20.12	2.012 xl0^{4}	2.012 xl0^{-2}	792	66	22	1.250 xl0^{-2}	1.086 xl0^{-2}
furlong	201.2	2.012 xl0^{5}	0.201	7920	660	220	1.250 xl0^{-1}	1.086 xl0^{-1}

Table 16.2: Length conversion factors

To convert to: / from:	sq m	sq cm	sq km	ha	sq in	sq ft	sq yd	ac
	multiply by							
square metres (m^2)	1	10000	1 xl0^{-6}	0.0001	1550	10.76	1.196	2.471 x10^{-4}
square centimetres (cm^2)	0.0001	1	1.000 x10^{-10}	1 xl0^{-8}	0.155	1.076 x10^{-3}	1.196 xl0^{-4}	2.471 x10^{-8}
square kilometre (km^2)	l xl0^{6}	1 x10^{10}	1	100	1.55 xl0^{9}	1.076 xl0^{7}	1.196 xl0^{6}	247.10516
hectares (ha)	10000	1 x108	0.01	1	1.55 xl0^{7}	1.076 xl0^{5}	1.196 xl0^{4}	2.471
square inches (in)	6.452 x10^{-4}	6.452	6.452 xl0^{-10}	6.452 x10^{-8}	1	6.944 x10^{-3}	7.716 xl0^{-4}	1.594 xl0^{-7}
square feet (fr)	0.0929	929	9.290 x10^{-8}	9.29 xl0^{-6}	144	1	0.1111	2.296 x10^{-5}
square yards (yd)	0.8361	8361	8.361 xl0^{-7}	8.361 xl0^{-5}	1296	9	1	2.066 xl0^{-4}
acres (ac)	4046.86	4.047 xl0^{7}	4.047 xl0^{-3}	0.4047	6.273 xl0^{6}	4.356 xl0^{4}	4840	1

Table 16.3: Area conversion factors

To convert to:	m^3	cc	l	in^3	ft^3	yd^3	US gal	IMP gal	Bbl (oil)
from:	*multiply by*								
cubic metres (m)	1	1×10^{6}	1000	61020	35.31	1.308	264.2	220	6.290
cubic centimetres (cc)	1×10^{-6}	1	0.001	6.102×10^{-2}	3.531×10^{-5}	1.308×10^{-6}	2.642×10^{-4}	2.2×10^{-4}	6.290×10^{-6}
lires (l)	0.001	1000	1	61.019886	0.0353147	1.308×10^{-3}	0.2641722	0:2199692	6.290×10^{-3}
cubic inches (in)	1.639×10^{-5}	16.388	0.0164	1	5.787×10^{-4}	2.143×10^{-5}	4.329×10^{-3}	3.605×10^{-3}	1.031×10^{-4}
cubic feet (ft^3)	2.832×10^{-2}	28317	28.32	1728	1	3.704×10^{-2}	7.481	6.229	0.1781
cubic yard (yd)	0.765	7.646×10^{5}	765	46656	27	1	201.97	168.18	4.809
US gallons (USgal)	3.785×10^{-3}	3785	3.785	231	0.1337	4.951×10^{-3}	1	0.833	2.381×10^{-2}
Imperial gallons (Impgal)	4.546×10^{-3}	4546	4.546	277.4	0.161	5.945×10^{-3}	1.20	1	2.859×10^{-2}
barrels (bbl)	0.159	1.590×10^{5}	159	9701	5.615	2.079×10^{-1}	42	35	1

Table 16.4: Volume conversion factors

To convert to:	kg	g	t	oz	lb	cwt	st	ltv
from:	*multiply by*							
kilogram (kg)	1	1000	1×10^{-3}	35.27	2.205	1.968×10^{-2}	1.102×10^{-3}	9.842×10^{-4}
grams(g)	0.001	1	1×10^{-6}	3.527×10^{-2}	2.205×10^{-3}	1.968×10^{-5}	1.102×10^{-6}	9.842×10^{-7}
tonne (metric ton) (t)	1000	1×10^{6}	1	35274	2205	20	1.102	0.984
once (oz)	2.835×10^{-2}	28.35	2.835×10^{-5}	1	0.0625	5.580×10^{-4}	3.125×10^{-5}	2.79×10^{-5}
pound (lb)	0.4536	453.6	4.536×10^{-4}	16	1	8.929×10^{-3}	5×10^{-4}	4.464×10^{-4}
hundredweight (cwt)	50.80	5.080×10^{4}	5.080×10^{-2}	1792	112	1	0.056	0.05
short ton (st)	907.2	9.072×10^{5}	0.907	32000	2000	17.86	1	0.893
long ton (lt)	1016	1.016×10^{6}	1.016	35840	2240	20	1.12	1

Table 16.5: Mass conversion factors

To convert to:	Pa	kPa	bar	mb	atm	mmHg	inHg	psi	ftH_2O
from:	*multiply by*								
pascals[1] (Pa)	1	0.001	1×10^{-5}	0.01	9.869×10^{-6}	7.501×10^{-3}	2.953×10^{-4}	1.450×10^{-4}	3.346×10^{-4}
kilopascals (kPa)	1000	1	0.01	10	9.869×10^{-3}	7.50	0.295	0.145	0.335
bar	1×10^{-5}	100	1	1000	0.987	750	29.53	14.50	33.46
millibar (mb)	100	0.1	0.001	1	9.869×10^{-4}	0.750	1953×10^{-2}	1.450×10^{-2}	3.346×10^{-2}
atmospheres (atm)	1.013×10^{5}	101.325	1.01325	1013.25	1	760	29.92	14.70	33.90
mm of Mercury[2] (mmHg(°C))	133.32	0.133322	1.333×10^{-3}	1.33322	1.316×10^{-3}	1	3.937×10^{-2}	1.934×10^{-2}	4.460×10^{-2}
inches of Mercury (inHg(°C))	3386.4	3.386	3.386×10^{-2}	33.8639	3.342×10^{-2}	25.4	1	0.491	1.133
pounds per square inch (psi)	6894.8	6.895	6.895×10^{-2}	68.95	6.805×10^{-2}	51.715	2.036	1	2.307
feet of water @ 60°F (ftH_2O)	2989	2.989	2.989×10^{-2}	29.89	2.950×10^{-2}	22.4	0.883	0.434	1

(1) Sometimes referred to explicitly as Newtons per square metre (N/m^2); (2) Sometimes referred to as Torr

Table 16.6: Pressure conversion factors

To convert to: / from:	m/s *multiply by*	cm/s	m/min	kph	ft/s	ft/min	mph	knots
metres per second (m/s)	1	100	60	3.60	3.28	196.9	2.237	1.943
centimetres per second (cm/s)	0.01	1	0.600	0.036	0.0328	1.969	0.0224	0.019
metres per minute (m/min)	0.0167	1.667	1	0.060	0.0547	3.281	0.0373	0.0324
kilometres per hour (kph)	0.278	27.778	16.667	1	0.9113	54.68	0.6214	0.5396
feet per second (ft/s)	0.305	30.48	18.29	1.0973	1	60	0.6818	0.5921
feet per minute (ft/min)	5.080 xl0^{3}	0.508	0.3048	0.0183	0.0167	1	0.0114	0.0099
miles per hour (mph)	0.447	44.70	26.82	1.6093	1.4667	88	1	0.8684
knots	0.515	51.48	30.89	1.8532	1.6889	101.3	1.152	1

Table 16.7: Velocity conversion factors

To convert to: / from:	cumec *multiply by*	l/s	cusec	gal/min	bpd
cubic metres per second (cumec)	1	1000	35.31	1.320 xl0^{4}	5.435 xl0^{5}
litres per second (l/s)	0.001	1	3.531 xl0^{-2}	13.20	543.5
cubic feet per second (cusec)	2.832 xl0^{-2}	28.32	1	373.7	15389
Imperial gallons per minute (gal/min)	7.577 xl0^{-5}	7.577 xl0^{-2}	2.676 xl0^{-3}	1	41.18
Barrels per day (bpd)	1.840 xl0^{-6}	1.840 xl0^{-3}	6.498 xl0^{-5}	2.429 xl0^{-2}	1

Table 16.8: Flowrate conversion factors

To convert to: / from:	kg/m^3 *multiply by*	kg/l	g/cc	lb/ft^3
kilograms per cubic metre (kg/m^3)	1	0.001	0.001	0.0624
kilograms per litre (kg/l)	1000	1	1	62.428
grams per cubic centimetre (g/cc)	1000	1	1	62.428
pounds per cubic foot (lb/ft^3)	16.02	1.602 xl0^{-2}	1.602 xl0^{-2}	1

Table 16.9: Density conversion factors

Specific Gravity	Litres	Cubic metres	Imperial gallons	US gallons	Barrels	Barrels per day	API gravity
50	2002	2.002	440	529	12.59	0.0345	–
55	1820	1.820	400	481	11.45	0.0314	–
60	1668	1.668	367	441	10.49	0.0288	–
65	1540	1.540	339	407	9.69	0.0265	86.19
70	1430	1.430	315	378	8.99	0.0246	70.64
75	1334	1.334	294	353	8.39	0.0230	57.17
80	1251	1.251	275	331	7.87	0.0216	45.38
85	1177	1.177	259	311	7.41	0.0203	34.97
90	1112	1.112	245	294	7.00	0.0192	25.72
95	1053	1.053	232	278	6.63	0.0182	17.45
100	1001	1.001	220	264	6.30	0.0173	10.00
105	953	0.953	210	252	6.00	0.0164	3.26

Table 16.10: Volume of liquids of different specific gravities contained in one tonne

Specific Gravity	per litre	per cubic metre	per Imperial gallon	per US gallon	per barrel	per barrel per day	API gravity
50	0.500	500	2.275	1.894	79.5	29,000	–
55	0.550	550	2.502	2.083	87.5	31,900	–
60	0.600	600	2.730	2.273	95.5	34,800	–
65	0.651	651	2.957	2.462	103.4	37,700	86.19
70	0.701	701	3.185	2.652	111.4	40,700	70.64
75	0.751	751	3.412	2.841	119.3	43,600	57.17
80	0.801	801	3.640	3.030	127.3	46,400	45.38
85	0:851	851	3.867	3.220	135.2	49,400	34.97
90	0.901	901	4.095	3.409	143.2	52,300	25.72
95	0.951	951	4.322	3.599	151.2	55,200	17.45
100	1.001	1001	4.550	3.788	159.1	58,100	10.00
105	1.051	1051	4.777	3,977	167.0	61,000	3.26

Table 16.11: Mass of liquids of different specific gravities in kilograms

References & Data Sources

References for specific data sources are listed in each chapter as they occur. This section lists general sources consulted in producing this publication, which can be used by those seeking additional information not covered in this document.

Since the publication of the second edition in 1993, there has been an explosive growth in web-based information sources. While this makes access to data easy, readers should be aware that the quality of the information on offer varies enormously. Sites such as Wikipedia (www.wikipedia.org) are an excellent starting point, but pages should be checked for independent sources and, if necessary, confirmed at other sites.

Web addresses given in this section can be considered authoritative, but no guarantee can be given as to the accuracy of information obtained from the sites listed.

Note that, as with all web links, addresses may change over time. All links were active as of March 2008.

Chapter 2: Units and Energy Conversion Factors

Data reproduced from:

- Baines, J T (ed.), 1993. *New Zealand Energy Information Handbook* (Second Edition), Taylor Baines and Associates, Christchurch;

supplemented by data from:

- the Bureau International Poids et Mesures (www.bipm.org [English version]) and
- the International Energy Agency (www.iea.org).

Chapter 3: Coal

Data obtained from:

- the Coal Association of New Zealand (www.coalassociation.org);
- Solid Energy (www.coalnz.com);
- Crown Minerals, Ministry of Economic Development (www.crownminerals.govt.nz);
- ASTM (www.astm.org); and
- Ministry for the Environment (www.mfe.govt.nz).

Chapter 4: Natural Gas

Data obtained from:

- the Ministry of Economic Development (www.med.govt.nz);
- Vector Ltd. (www.vector.co.nz);
- the Gas Association of New Zealand (www.ganz.org.nz); and
- Standards New Zealand (www.standards.co.nz).

Chapter 5: Petroleum

Data obtained from:

- the Ministry of Economic Development [Energy Greenhouse Gas Emissions 2005] (www.med.govt.nz);
- New Zealand Refining Company (www.nzrc.co.nz);
- Guyol, NB (1977), *Energy Interrelationships - a Handbook of Tables and Conversion Factors for Combining and Comparing International Energy Data*, US Federal Energy Administration, Washington; and
- Glasstone, S (1982), *Energy Deskbook*, US Department of Energy, Oak Ridge.

Chapter 6: Geothermal

Data obtained from:

- White, B (2006), *An Assessment of Geothermal Direct Heat Use in New Zealand*. (www.nzgeothermal.zorg.nz/publications/Reports/NZGADirectHeatAssessmentReport_2006.pdf);
- Lawless J V and Lovelock B G, 2001. "New Zealand's geothermal resource base", *6th Annual Seminar, New Zealand Geothermal Association*, Taupo;
- NZGA 1 (no date) *New Zealand Geothermal Association: Development Potential*, on NZGA website: www.nzgeothermal.org.nz/geothermal_energygeothermal_development.asp);
- NZGA 2 (no date), *New Zealand Geothermal Association: Emissions*, on NZGA website: www.nzgeothermal.org.nz/environmental/emissions.asp; and
- the New Zealand Geothermal Association Inc (www.nzgeothermal.org.nz).

Chapter 7: Wood

Data obtained from:

- Tillman, D (1980), "Review of mechanisms associated with wood combustion", *Wood Science* 13(4);
- Miller, W and Young, G (1989), "Wood properties of firewood", *FRI Bulletin* 137, Rotorua;
- *Energy Data File* (2007), Ministry of Economic Development (www.med.govt.nz);
- Solid Energy (www.solidenergy.co.nz)

Chapter 8: Energy from Waste

Data obtained from:

- Ministry of Agriculture and Forestry (www.maf.govt.nz); and
- International Solid Waste Association (www.iswa.org).

Chapter 9: Solar

Data obtained from:

- Baines, JT and Smith, DJ (1982), *Environmental Energy Flows in the New Zealand Economic System*, Centre for Resource Management, Lincoln University;
- NIWA (www.niwa.cri.nz); and
- the Sustainable Electricity Association of New Zealand (www.seanz.org.nz).

Chapter 10: Wind

Data obtained from:

- Transpower (www.transpower.co.nz);
- NIWA (www.niwa.cri.nz); and
- the NZ Wind Energy Association (www.windenergy.org.nz).

Chapter 11: Oceans

Data obtained from:

- EECA (www.eeca.govt.nz); and
- NIWA (www.niwa.cri.nz).

Chapter 12: Emerging Forms of Energy

Data obtained from:

- Wickramanayake, WP (1981), *Diesel Substitutes – Alternative Fuels for a Diesel Engine*, ME Thesis, CAPE, University of Canterbury;
- Sims, R *et al* (no date), *Tallow, Rapeseed Oil and their Esters as Diesel Fuel Extenders*, Research Publication 2, Massey University Agricultural Research Foundation;
- Pecher, IA and Henrys, SA (2003), *Potential gas reserves in Gas Hydrate Sweet Spots on the Hikurangi Margin, New Zealand*, Institute of Geological & Nuclear Sciences;

– EECA (www.eeca.govt.nz); and

– Ministry of Economic Development (www.med.govt.nz).

Chapter 13: Electricity

Data obtained from:

– Transpower (www.transpower.co.nz);

– *Energy Data File* (2007), Ministry of Economic Development (www.med.govt.nz);

– Department of Electrical and Computer Engineering, University of Canterbury (www.elec.canterbury.ac.nz);

– the New Zealand Wind Energy Association (www.windenergy.org.nz); and

– CAENZ (www.caenz.com).

Chapter 14: Energy Demand and Efficiency

Data obtained from:

– Isaacs NP, Camilleri M, French L, Pollard A, Saville-Smith K, Fraser R, Rossouw P and Jowett JH, 2006. *Energy Use in New Zealand Households: Report on the Year 10 Analysis for the Household Energy End-use Project (HEEP)*. BRANZ Ltd., Judgeford, Porirua (Study Report 155 - available from www.branz.co.nz);

– Ministry of Economic Development (www.med.govt.nz);

– EECA (www.eec a.govt.nz);

– Ministry of Transport (www.transport.govt.nz); and

– CAENZ (www.caenz.com).

Chapter 15: Storage

Data obtained from:

– Electricity Storage Association (www.energystorage.org);

– Energy Storage Systems, Sandia National Laboratories (www.sandia.gov/ess/index.html); and

– CAENZ (www.caenz.com).

Chapter 16: General Physical Conversion Factors

Data reproduced from:

– Baines, J T (ed.), 1993. *New Zealand Energy Information Handbook* (Second Edition), Taylor Baines and Associates, Christchurch;

checked by reference to:

– the National Institute of Standards and Technology website (http://physics.nist.gov) and

– Wikipedia (http://en.wikipedia.org/wiki/Conversion_of_units).

General Reference

The following list is of organisations (both New Zealand and international) with energy information data available on their websites. This list is by no means exhaustive, rather a starting point for those readers seeking further information. Site access was confirmed March 2008.

New Zealand

Bioenergy Association of New Zealand
www.bioenergy.org.nz

Crown Minerals (MED)
www.crownminerals.govt.nz

Electricity Commission
www.electricitycommission.govt.nz

Energy Efficiency & Conservation Authority (EECA)
www.eeca.govt.nz

Energy Federation of New Zealand
www.energyfed.org.nz

Energy Library
www.energylibrary.co.nz

National Energy Research Institute
www.neri.org.nz

National Institute of Water & Atmospheric Research (NIWA)
www.niwa.cri.nz

New Zealand Centre for Advanced Engineering
www.caenz.com

New Zealand Climate Change Office
www.climatechange.govt.nz

New Zealand Ministry of Agriculture and Forestry
www.maf.govt.nz

New Zealand Ministry of Economic Development
www.med.govt.nz

New Zealand Ministry for the Environment
www.mfe.govt.nz

New Zealand Photovoltaic Association
www.photovoltaics.org.nz

New Zealand Wind Energy Association
www.windenergy.org.nz

International

Department of Energy (US)
www.energy.gov

Energy Efficiency & Renewable Energy Network (US)
www.eere.energy.gov

EPRI Energy Search
www.energysearch.com

Global Energy Marketplace (GEM)
www.crest.org/gem.html

International Energy Agency (IEA)
www.iea.org

Glossary

AMWS	Annual Mean Wind Speed.
ANZSIC	Australia-New Zealand Standard Industrial Classification.
API	American Petroleum Institute.
ASTM	American Society for Testing Materials.
Aviation fuels	Avgas, Avtur, Jet-A1 and Jet-4 aviation fuels, light kerosene and premium kerosene.
Biogas	Gas produced from the anaerobic digestion of sewage and industrial waste. Includes landfill gas and sewage. Biogas is mostly a mixture of methane and carbon dioxide.
Bunker Fuels	Bunker fuels are fuels used in international marine transportation.
CARB	California Air Resources Board.
CBM	Coalbed Methane.
Cetane Number	A measure of the combustion quality of diesel fuel during compression ignition. New Zealand regulations require a minimum cetane number of 51 for diesel fuels (as of 2007).
CFPP	Cold Filter Plugging Point.
CI	Compression Ignition.
CNG	*see* Compressed Natural Gas.
$CO_{2\text{-}e}$ or CO_2 equivalent	Measures the combined climate changing potential of emissions of multiple greenhouse gases. Emissions of each gas are converted to an amount of CO_2 that would cause the same climate change impact and summed.
Cogeneration	The simultaneous or sequential production of two or more forms of useful energy from a single primary energy source.
Coke	The solid product obtained from carbonisation of coal, principally coking coal, at high temperature. It is low in moisture and volatile matter. Coke is used mainly in the iron and steel industry acting as energy source and chemical agent.
Commercial	The commercial sector includes non-manufacturing business establishments such as hotels, motels, restaurants, wholesale businesses, retail stores and health, social and educational institutions.

Compressed Natural Gas	(CNG) Natural gas which has been compressed, or contained under pressure, in a small volume. Mainly used as a transport fuel.
Condensate	A light crude oil which is present in natural gas deposits.
Consumer energy	The amount of energy consumed by final users. It excludes energy used or lost in the process of transforming energy into other forms and in bringing the energy to the final consumers.
COP	Coefficient of Performance.
Crude oil	A mineral oil consisting of a mixture of hydrocarbons of natural origins, yellow to black in colour, of variable density and viscosity.
CTL	Coal to Liquids.
DC	Direct Current.
Diesel	Automotive gas oil, marine diesel and blended heating oil.
Emission Factor	A unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g. grams of carbon dioxide emitted per barrel of fossil fuel consumed). It is used to calculate the amount of greenhouse gas emitted – the product of the emissions factor and the amount of energy used.
Energy balances	The ratio of total useful output to energy input.
Feedstock	This is raw material directly used in production.
Fossil fuels	Coal, natural gas, LPG, crude oil and fuels derived from crude oil (including petrol and diesel). They are called fossil fuels because they have been formed over long periods of time from ancient organic matter.
Fractionation	A distillation process used for the separation of the various components of a liquid mixture.
F-T	Fisher-Tropsch.
FTP	Federal Test Procedure.
Fuel oil	Light fuel oil, heavy fuel oil and other fuel oils.
Gas production	Defined as the quantity after the first separation point. It includes gas reinjected, flaring, own use, losses and LPG extracted.
GCV	Gross Calorific Value.
GHG	Greenhouse Gas.

Greenhouse Gas	Atmospheric gases that increase the earth's temperature by absorbing outgoing infrared radiation from the earth's surface. Man-made greenhouse gases that have a direct effect are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Indirect greenhouse gases which react to form direct greenhouse gases in a relatively short time include carbon monoxide (CO), other oxides of nitrogen (NO_x), and non-methane volatile organic compounds (NMVOCs). Water vapour (H_2O) is also a greenhouse gas, however its concentration in the atmosphere is naturally regulated.
GTL	Gas to Liquids.
Hs	Significant Wave Height.
HVAC	Heating Ventilation Air-Conditioning.
IEA	International Energy Agency.
Industrial	Refers to all uses except Residential and Commercial.
IPCC	Intergovernmental Panel on Climate Change.
IPS	International Pyrheliometric Scale.
ISO	International Organisation for Standardisation.
Lat	Latitude.
LFG	Landfill Gas.
Line losses	For electricity, this refers to the losses incurred in conveying electricity to bulk and retail consumers. It results mainly from transformer and other losses on the network.
Liquefied Petroleum Gas	(LPG) Consists of propane (60%) and butane (about 40%).
Lon	Longitude.
LPG	*see* Liquefied Petroleum Gas.
MSW	Municipal Solid Wastes.
National transport	Includes road, off-road and rail land transport, coastal shipping and national air transport, but excludes international transport.
Natural gas	Consists mainly of methane occurring naturally in underground deposits. It may be associated or free gas.
NCV	Net Calorific Value.
Network	For electricity, this refers to the interconnected transmission or distribution lines or cables and associated power

	transformers for supplying power to customers.
NG	*see* Natural Gas.
Non-energy use	Use of primary energy for other purposes (e.g., bitumen for roads) and natural gas used as feedstock for the production of methanol and ammonia/urea.
NZS	New Zealand Standards.
Oil	Oil includes crude oil, condensate and oil products.
OTEC	Ocean Thermal Energy Conversion.
PM	Particulate Matter.
PO.DAAC	Physical Oceanography Distributed Active Archive Center.
Primary energy	Energy, as it is first obtained from natural sources.
PSFO	Power Station Fuel Oil.
Recoverable reserves	Estimates of the total amounts of oil and gas that can be extracted during the lifetime of each field. These may differ from initial reserves estimates made at the commencement of production.
Refinery products	Include refinery naphtha, mid distillate and motor gasoline blending components, eg, alkylate mix, offgrade regular, offgrade premium, reformate, cracked spirit. Synfuels used as refinery feedstock are also included in this category.
Reserves	Oil and gas reserves are expected reserves, estimated as 'proven and probable' or P50 (ie, with a greater than 50% probability of being technically and economically producible) reserves by the field operators.
Residential/domestic	This refers to each separately metered private dwelling, i.e., private houses. It excludes hotels, hostels and institutions (which are included in the commercial sector), but does include normally unoccupied holiday homes and beach houses.
Separation	Splitting wellhead gas into a gas stream and a liquid stream.
Sp. Gr.	Specific Gravity.
Specific energy	Energy per unit mass.
Specific gravity	Ratio of the density of the material of interest to the density of water.
SST	Sea Surface Temperature.

Syn	Synthetic.
Total primary energy supply	(TPES) The amount of energy available for use in New Zealand for energy transformation and end use. It includes energy as it is first obtained from natural sources. By convention, fuels used for international transport are excluded from total primary energy supply.
Tp	Peak Period.
TS	Total Solids.
Wobbe Index	A number indicating the interchange ability of fuel gases. It relates fuel gas heating characteristics in a manner that is useful for the blending of fuel gases, or to obtain a constant heat flow from a gas of varying composition.
Wood residues	Includes arisings, hog fuel, bark and black liquor.
Wood	Includes wood supplied as fuel, wood waste and residues.

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